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Second Series.

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THE

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SECOND SERIES,

COMPRISING

TREATISES

ON

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METALLURGY
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ORYCTOLOGY
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CONTENTS.

PREFACE.

CHEMISTRY.

Definition, 3—Objects of the Science, *ib.*—Attraction of Aggregation and Attraction of Composition, 4—Modes of Aggregation, 5—Effect of Chemical Combination, 6—Simple and Compound Substances, 9—Table of Simple Substances, 11—Oxygen, 13—Nitrogen, 14—Hydrogen, *ib.*—Chlorine, 15—Carbon, 16—Silicon, *ib.*—Boron, Sulphur, Phosphorus, 17—Iodine, Bromine, Fluorine, 18—Selenium, 19—Metals, *ib.*—Chemical Affinity, 21—Laws of Chemical Affinity, 22—Elective Attraction, 23—Divisibility of Matter, 24—Combustion, 28—Influence of Heat on Solution, 33—Electricity, 35—Metallic Crystallizations, 41—Animal Electricity, 43—Spontaneous Combustion of the Human Body, 44—Theory of Definite Proportions, 48—Atomic Weights of Bodies, 49—Dr. Wollaston's Scale of Equivalents, 53—Simple and Compound Electrive Attraction, 58—Primary and Secondary Chemical Compounds, 62—Observations on Simple Bodies and their Primary Compounds, 66—Table of Binary Compounds of Non-metallic Elements, 67—Oxygen, Oxides, and Acids, 70—Chlorine and Chlorides, 75—Iodine, Iodic Acid, 78, 80 Bromine, Bromic Acid, 81, 82—Fluorine, *ib.*—Hydrogen, 84—Water, 85—Muriatic Acid, 88—Nitrogen, 92—Oxides of Nitrogen, 94—Acids, 96—Chloride of Nitrogen, 97—Ammonia, 98—Carbon, Diamond, 99—Carbonic Oxide, 100—Acids, 101—Compounds of Hydrogen and Carbon, 108—Cyanogen, 110—Boron, Boracic Acid, 111, 112—Silicon, 113—Silica, *ib.*—Phosphorus, 116—Oxides and Acids, 118—Combinations with Hydrogen, 121—Sulphur, 123—Acids, 124—Sulphurets, 128—Selenium, 129—Acids, 130—Metallic Elements, 132—Classification of Metals, 133—Tables of Binary Combinations of Metallic and Non-metallic Elements, 134, 143, 153—Arsenic, 137—Antimony, Columbium, Titanium, 138—Chrome, Molybdena, Tellurium, 139—Tungsten, Vanadium, Uranium, Manganese, 140—Cobalt, 141—Tin, 142—Potassium, 144—Sodium, 146—Lithium, 147—Baryum, Calcium, 148—Strontium, 149—Magnesium, Aluminum, 150—Zirconium, Glucinum, 151—Yttrium, Thorinum, 152—Iron, 155—Nickel, 156—Zinc, Cadmium, Cerium, Lead, Copper, 157—Bismuth, Mercury, 158—Silver, Gold, Platina, 159—Palladium, Rhodium, Iridium, and Osmium, 160.

METALLURGY.

Definition, 163—MINERAL DEPOSITS AND MINES, 164—Mineral Veins, 165—Metallic Ores and their Localities, 170-174—ART OF MINING, 174-188—DOCIMASY, 188—Assaying by the Dry Method, 190—Assaying by the Moist Method, 193—Reduction of Metallic Ores, 195—Gold, 196—Silver, 198—Platina, 199—Mercury, 201—Iron, *ib.*—Tin, 204—Copper, 205—Lead, 207—Zinc, 208—Alloys, 210-214.

MINERALOGY.

Preliminary Observations, 217—Classification of Minerals, 219—Properties of Minerals, 220—Constituents of Mineral Substances, 224—Arrangement, 225—Table of Mineral Classes, 228—Electro-positive Native Metals, 229-232—Electro-negative Substances and their Non-oxidized Combinations, 232—Tellurium and Tellurets, *ib.*—Arsenic and Arseniurets, 233—Carbon and

Carburets, *ib.*—Selenium and Seleniurets, 234—Sulphur and Sulphurets, 235—Oxides of Electro-positive Metals, 240-242—Oxides and Oxacids of Electro-negative Substances, 242—Alumina and Aluminates, *ib.*—Silica and Silicates, 243-252—Oxide of Titanium and Titanates, 253—Columbic Acid and Columbates, *ib.*—Antimonic Acid and Antimoniates, 254—Tungstates, *ib.*—Molybdic Acid and Molybdates, 255—Chromic Acid and Chromates, *ib.*—Vanadic Acid and Vanadiates, 256—Boracic Acid and Borates, *ib.*—Carbonates, 257—Arsenious Acid and Arseniates, 261—Phosphates, 262—Nitrates, 264—Sulphates, *ib.*—Fluorides, 267—Chlorides, *ib.*—Organo-chemical Substances, 268—CRYSTALLOGRAPHY, 269—Figures of Crystals, 270—Isomorphism, 273—Haüy's Theory of Crystallization, 275—Primitive Forms, 277—Law of Decrements, 281—Goniometry, 283—Crystallometrical System of Mohs, 285.

GEOLOGY.

Introductory Remarks, 289—Cosmogonical Speculations, 290-294—Theories of Werner and Hutton, 295—Researches of Cuvier, 297—Progress of Geological Science, 298—Figure of the Earth, 300—Density, 302—Speculations on the Central Structure of the Earth, 303—Subterranean Temperature, 306—Thermal Springs, 311—Temperature of the Atmosphere, 313—State of the Earth's Surface, 317—State of the Crust of the Earth, 321—Modifying Action of Existing Causes, 323—Influence of the Atmosphere, 324—Deluges of Sand, 333—Hurricanes, 334—Influence of Water, 335—Destructive Effects, *ib.*—Land-floods, 339—Alluvial Islands, 341—Debacles, 343—Landslips, 345—Bursting of Bogs and Mosses, 347—Action of Frozen Water, 349—Effect of Waves and Breakers, 350—Deposits from Hot Springs, 353—Submarine Formations, 355—Earthquakes, 360—Volcanos, 364—Causes of these Phenomena, 370—Remarks on the Analogy between Ancient and Modern Disturbances of the Earth's Surface, 372-376—Formation of Valleys, 377—Erratic Blocks, 379—Elevation of Mountains, 381—Chemical Structure of Rocks, 385—Mechanical Structure, 391—Classification and Arrangement of Rocks, 398—Table of Groups, Formations, and Rocks, 401—ORYCTOLOGY, 406—Modes of Fossilization, 407—Geological Arrangement of Minerals and Fossils, 416—Primordial Rocks and their Minerals, 418—

Fossil Remains in Submedial Rocks, 419—in Medial Rocks, 423—in Supermedial Rocks, 431—in Tertiary Rocks, 438—in Alluvial Deposits and Bone Caverns, 441—Description of Geological Map of England and Wales, 447—Coal Formations, *ib.*

METEOROLOGY.

Preliminary Remarks, 451—General Observations on the Atmosphere, 453—Variations of Atmospheric Pressure, 455—WINDS, 456—Causes of Winds, 457—Periodical, Variable, and Local Winds, 459-462—Velocity of Winds, 462—HYGROMETRY, 463—Saussure's Hygrometer, 464—Daniell's and other Dew-point Hygrometers, 465, 466—Clouds, 467—Formation, 468—Constitution, 469—Modifications, 470—Cirrus, 471—Cumulus, *ib.*—Stratus, 472—Cirrocumulus, *ib.*—Cirrostratus, 473—Cumulostratus, *ib.*—Nimbus, 474—Rain, *ib.*—Snow, 475—Hail, 476—Dew, *ib.*—Hoar-frost, 477—Ground-ice, 478—Optical and Electrical Phenomena, 479—Aerolites, 480.

PREFACE.

ENCOURAGED by the favourable reception from the Public of a small volume on the first principles of Natural Philosophy, published last year, under the title of THE BOOK OF SCIENCE, and by the flattering manner in which it was noticed by critical journalists, I have been induced to collect and arrange the materials of the present work. It may, perhaps, be considered as a proper sequel to the preceding publication: for, while that affords some general views of the state of the physical sciences, it is the object of this volume to furnish corresponding notices of the elements of Chemistry, and some of the arts and sciences immediately connected with it.

Some of the subjects here introduced to the notice of the youthful reader, have previously employed the pens of many able writers. That is especially the case with Chemistry; so that with respect to that branch of knowledge, a new elementary work was scarcely requisite. In appreciating the merit of this volume, however, it must be taken collectively, and therefore the tract on Chemistry should be considered as designed to form an appropriate introduction to the subsequent portion of the work, and the whole may serve as a guide to researches into the structure and composition of the inorganized parts of the earth.

Geology, which in an especial manner relates to the present state of the earth's surface and the crust beneath it, appears at present to have become one of the most attractive objects of public attention connected with the physico-chemical sciences. There are several very valuable treatises on Geology which have been recently published in the English and French languages, among the former of which are the highly popular works of Lyell and De la Beche. Those gentlemen are celebrated as cultivators of the science they have illustrated by their writings. My utmost ambition would be gratified in finding that I had produced a tract that might serve, in any degree, to render their elaborate productions more easily accessible to the youthful or uninformed reader.

The necessity of laying a foundation for geological studies, by forming a previous acquaintance with Chemistry and Mineralogy, has been repeatedly pointed out; but I am not aware that any work containing a connected body of information relative to Geology and the kindred sciences has hitherto appeared, except a small volume by the late Mr. W. Phillips, grounded on a series of lectures which he delivered in or near the metropolis. Mr. Phillips possessed a fund of practical knowledge and scientific intelligence to which I have no pretensions. And I take this opportunity to offer a tribute of admiration to the memory of that highly-distinguished cultivator of chemical science. I also acknowledge that from his *Outlines of Mineralogy and Geology*, I have derived important assistance, especially in that portion of my work that relates to Metallurgy. Notwithstanding the rapid progress of the sciences of which it treats, and the time that has elapsed since the last edition of the *Outlines* appeared, it still retains its value. But the publication of another elementary treatise on the subjects in question, can hardly be deemed superfluous in the present state of science; and therefore this compilation it is hoped may be found deserving of the same patronage that was extended to the former volume.

Leaving now the literary portion of this work to speak for itself, I must beg to be allowed to direct the attention of the student to the graphic illustrations, in the merit of which I can, of course, claim no share. One of these illustrative cuts has been executed in a peculiar manner, exhibiting a specimen of wood engraving printed in colours. The artist, Mr. Baxter, has thus been enabled to furnish representations of the forms and appearances of clouds, which for accuracy and effect may compete with drawings in water-colours.

CHEMISTRY.

THE WONDERFUL AND SUDDEN TRANSFORMATIONS WITH WHICH CHEMISTRY IS CONVERSANT, THE VIOLENT ACTIVITY OFTEN ASSUMED BY SUBSTANCES USUALLY CONSIDERED THE MOST INERT AND SLUGGISH, AND, ABOVE ALL, THE INSIGHT IT GIVES INTO THE NATURE OF INNUMERABLE OPERATIONS WHICH WE SEE DAILY CARRIED ON AROUND US, HAVE CONTRIBUTED TO RENDER IT THE MOST POPULAR, AS IT IS ONE OF THE MOST EXTENSIVELY USEFUL, OF THE SCIENCES; AND WE SHALL, ACCORDINGLY, FIND NONE WHICH HAVE SPRUNG FORWARD, DURING THE LAST CENTURY, WITH SUCH EXTRAORDINARY VIGOUR, AND HAVE HAD SUCH EXTENSIVE INFLUENCE IN PROMOTING A CORRESPONDING PROGRESS IN OTHERS.

Sir John Herschel on the Study of Natural Philosophy.

CHEMISTRY.

Chemistry is the art whereby compound bodies are changed into simple ones, or simple bodies into compounds. The former of these processes is called Analysis or Decomposition, and the latter Synthesis or Composition. As a science, it is the province of Chemistry to determine the chemical relation of simple bodies, and the structure and chemical relations of compounds. Few of the operations of Chemistry, which are employed for the attainment of these objects, are either purely analytic or synthetic; a combination of these methods generally taking place in the processes of the chemist.

Different kinds of matter which are the objects of Chemistry possess certain active properties, such as gravity or weight, cohesion, elasticity, expansibility, magnetic attraction, &c. All these properties are but so many different modifications of attraction and repulsion.

Action, either attractive or repulsive, takes place between bodies situated at various distances from each other. Thus the attraction of gravitation operates at indefinite and immense distances; while the attraction of cohesion affects the particles of bodies only when placed in apparent contact. Repulsive action also takes place at different distances. Thus the repulsion between bodies which have been subjected to the influence of electricity or magnetism is sufficiently obvious to the sight; and that electric or magnetic substances which repel each other do not touch, may easily be perceived. The expansive power of heat on the other hand probably affects particles of matter nearly in contact with each other.

The various phenomena which constitute the objects of Chemistry, depend on the operation of those modifications of attractive and repulsive force, which act on particles of bodies placed at insensible distances from each other, and are so minute as not to be cognizable by our senses, even when assisted by the most powerful magnifying glasses.

There are two species of attraction which affect particles of matter when in apparent contact: 1. The Attraction of Aggregation, or Cohesion; 2. The Attraction of Composition. These powers both give way to the repulsive action of heat: but the former may also be overcome by mechanical force, which has no effect on the latter.

The Attraction of Aggregation operates differently on different bodies, so as to produce the various degrees of cohesive force or consistence observable among them. The forms under which bodies appear are reducible to three classes, viz.: Solids, Liquids, and Gases or Airs. These modifications of matter are influenced by the operation of mechanical pressure and the expansive force of heat, which seem to act as antagonist powers to each other. Some kinds of matter are capable of existing either in a solid, liquid, or gaseous state, under different degrees of atmospherical pressure and temperature. Thus water, by the abstraction of heat, becomes changed to ice; by the addition of heat, it is, on the other hand, changed to vapour; and that change is facilitated or impeded by lessening or increasing the atmospherical pressure. Mercury and several other substances exhibit analogous phenomena.

Many bodies, however, commonly exist under only one or two forms of aggregation. Common air and other bodies, distinguished from vapours by the designation of permanent gases, were formerly supposed to retain the gaseous form under all circumstances; but, from the experiments of Dr. Faraday and Mr. Perkins, it appears that atmospheric air, carburetted hydrogen, sulphuretted hydrogen, sulphurous acid, carbonic acid, protoxide of chlorine, nitrous oxide, cyanogen, ammonia, muriatic acid, and chlorine, all which, under common temperatures and pressures, are permanent gases, may be condensed to the liquid state by the joint operation of intense cold and powerful compression. However, oxygen, hydrogen, and some other gases have hitherto resisted all attempts to reduce them to the liquid state.* Several dense solids, as lead and glass, are readily melted by heat; but there are others, as wood, which, though speedily decomposed, when heated with access of air, cannot be liquefied. The facts already stated and others which might be adduced still lead to the conclusion that the solid, liquid, and gaseous states of bodies depend chiefly on their respective relations to temperature and pressure; and therefore the distinctions founded on those states or forms of matter do not furnish sufficient grounds for general arrangements of bodies in separate classes.

Some writers have treated of the chemical properties of gases or airs as an independent branch of science, under the appellation of Aërology; but the operation of bodies under their different forms are so intimately blended, and the condensation of gases is so commonly the effect of chemical combinations, that it seems by far most convenient not to separate Aërology from Chemistry, but to regard it as a subordinate section or subdivision of chemical science.

In solid and liquid substances, the powers of attraction and repulsion counterbalance each other; while the latter predominates in gaseous bodies. Some have supposed solidity to result from the preponderance of the force of attraction over the force of repulsion; but this opinion seems incompatible with the well-known fact of the expansion of water when it becomes solid. This and some other phenomena of a similar description, clearly show that the action of a repulsive force is not less obvious in solids than in fluids. They probably differ more in the arrangement of their particles, than in the manner in which those particles are united.

The peculiar province of Chemistry, as might be inferred from the preceding observations, is the study of the Attraction of Composition, or the investigation of the properties of bodies, not as respects their organization, mechanical construction, form, or consistence, but with a view to the discovery of their molecular composition, or the nature and mode of union of their component particles. Hence there must necessarily be a wide distinction between mechanical and chemical combination. Any substances may be mechanically combined by mere mixture, which occasions no destruction or essential alteration of the sensible properties of the mixed bodies: for the compound formed by the union of two or more substances which have no chemical action on each other, will always exhibit their joint properties, modified, perhaps, but not destroyed by their commixture. The effect of chemical combination is very different, for bodies chemically united often become completely deprived of the peculiar properties they previously possessed, and manifest new and sometimes very extraordinary powers, totally different from those of their constituent parts.

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* See Book of Science, pt. i. 2d ed. p. 186.

"If water be added to water, or salt to salt, the effect is an increase of quantity, but no change of quality. In this case, the mutual action of the particles is entirely mechanical. Again, if a blue powder and a yellow one, each perfectly dry, be mixed and well shaken together, a green powder will be produced; but this is a mere effect arising in the eye, from the intimate mixture of the yellow and blue light separately and independently reflected from the minute particles of each; and the proof is had by examining the mixture with a microscope, when the yellow and blue grains will be seen separate, and each quite unaltered. If the same experiment be tried with coloured liquids, which are susceptible of mixing without chemical action, a compound colour is likewise produced, but no examination with magnifiers is in that case sufficient to detect the ingredients; the reason obviously being, the excessive minuteness of the parts, and their perfect intermixture, produced by agitating two liquids together. From the mixture of two powders, extreme patience would enable any one, by picking out with a magnifier grain after grain, to separate the ingredients. But when liquids are mixed, no mechanical separation is any longer practicable; the particles are so minute as to elude all search. Yet this does not hinder us from regarding such a compound as still a mere mixture, and its properties are accordingly intermediate between those of the liquids mixed. But this is far from being the case with all liquids. When a solution of potash, for example, and another of tartaric acid, each perfectly liquid, are mixed together in proper proportions, a great quantity of solid saline substance falls to the bottom of the containing vessel, which is quite different from potash or tartaric acid, and the liquid from which it subsided offers no indications by its taste or other sensible qualities of the ingredients mixed, but of something totally different from either. It is evident that this is a phenomenon widely different from that of mere mixture; there has taken place a great and radical change in the intimate nature of the ingredients, by which a new substance is produced which had no existence before; and it has been produced by the union of the ingredients presented to each other, for when examined, it is found that nothing has been lost, the weight of the whole mixture being the sum of the weights mixed. Yet the potash and tartaric acid have disappeared entirely, and the weight of the new product is found to be exactly equal to that of the tartaric acid and potash employed, taken together, abating a small portion held in solution in the liquid, which may be obtained however by evaporation. They have therefore combined, and adhere to one another with a cohesive force sufficient to form a solid out of a liquid; a force which has been called into action by merely presenting them to each other in a state of solution."*

As it is the object of Chemistry to determine the composition of different substances, therefore if we could reduce all bodies to their elementary principles, and discover the proportions in which these principles must be combined in order to recompose such bodies, the science of Chemistry would be complete. This, however, is far from being the case, notwithstanding the extraordinary discoveries that have rewarded the labours of those philosophers who have paid attention to this important branch of knowledge. But though we allow that much remains to be achieved by future experimentalists ere Chemistry can be said to make any near approaches to perfection, yet it must be admitted, that the improvements which have taken place in this science in our own times are of no common importance, since its first principles have been fixed on the firm basis of experiment, and a luminous system, founded on facts, has superseded those obscure and hypothetical speculations which occur in the writings of the older chemical authors.

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* Herschel's Discourse on the Study of Natural Philosophy, pp. 297, 298.

Among the most important discoveries of modern philosophers, we may reckon those which relate to that inherent tendency which matter possesses to form new combinations. This property of matter gives rise to many of those operations of nature which we view without surprise, only because they are common; and it is not less concerned in several of the most striking and extraordinary phenomena of nature and art. Thus when we procure light or heat by burning any combustible substance, as for instance wood, chemical action takes place between the inflammable matter contained in the wood, and part of the air of the room in which the wood is burned; in consequence of which, a new kind of air is formed, the greater part of which flies off with the smoke. The respiration of animals affords another instance of chemical action. When air is taken into the lungs, a part of it combines with something which separates from the blood; in consequence of which combination, the air becomes altered in its properties, as must be obvious to every one who considers that the atmosphere of a crowded apartment, not properly ventilated, is soon rendered so noxious as to occasion considerable inconvenience, and even faintness, to those whose constitutions are delicate.

On taking a survey of the various bodies around us, we may observe, that some among them, which we reckon inert, because from the influence of habit or other causes they make but a slight impression on our senses, are yet endowed with active powers or properties, which render them capable of producing remarkable changes in other bodies. Thus water, which is insipid to the tongue, and which in its operation on living animals and vegetables acts slowly and almost imperceptibly, will yet, if placed in contact with a lump of salt or sugar, speedily reduce either from the solid to the liquid state. Atmospheric air, though it is necessary for the support of animal and vegetable existence, and gives rise to scarcely any sensations but such as depend on variations of temperature, yet this widely-extended gaseous body by its union with other substances, sometimes produces the most striking phenomena. Thus the explosion of fire-damp in coal-mines can only happen when the inflammable gas, so called, is mixed with a certain portion of common air.

One of the most obvious modes of distinguishing bodies is that which depends on their different degrees of density; whence the arrangement of substances into the respective classes called solids, liquids, and gases, already noticed. But these distinctions cannot be advantageously employed as the basis of a chemical classification of natural bodies, for reasons which have been already stated. Hence some other mode of discrimination and arrangement becomes requisite, and such a one may be most properly derived from considering the chemical relations of different kinds of matter, and the products derived from their action on each other.

There are some bodies which by no known mode of treatment, without addition, can be made to form more than one species of matter; for however they may be divided or subdivided, each particle still possesses the same chemical properties with the common mass, from which it was taken. There are comparatively but few bodies presented to us by nature in this isolated state; among the number may be mentioned, as examples, gold and the diamond. These, together with all other hitherto undecomposed bodies, must in the present state of chemical science be considered as elementary or simple substances. Were it practicable to procure and exhibit all the elements of bodies in a detached form, and to trace the various compounds resulting from their union, Chemistry would have attained perfection, and no object of inquiry would remain for future experimentalists. But notwithstanding the great acquisition of knowledge derived from the discoveries of our contemporaries, they have by no means enabled us to determine the boundaries of the field of science, but merely to form some conjectural ideas concerning its vast extent.

No correct general knowledge of the nature and properties of different substances can be acquired without instituting comparisons between them, whence we may discover the various points of similitude or contrast among them, which will enable us to arrange them in groups or classes, bearing certain relations to each other.

For the purposes of chemical inquiry, the most obviously convenient arrangement of bodies is that in which they are classed according to their composition, placing the simple bodies first in order, and then the compounds arising from the various combinations of the former.

According to the ancient philosophers, the simple bodies or elementary principles from which all the varieties of matter are composed, were but four, namely, Fire, Air, Water, and Earth. This notion, after having for ages formed a part of the creed of the learned, has been completely exploded by the light of modern science, though it is not yet extinct among the vulgar. The alchemical writers of the middle ages added to these principles some others, as Salt, Sulphur, and Mercury; to which terms, however, they attached ideas very different from those that belong to them at present, and into the nature of which we shall not stop to inquire.

Some of the alleged elements of the older chemists are now known to exist only in imagination, and others are ascertained to be by no means simple substances: thus Air is found to consist of two different elastic fluids or gaseous bodies, which may be separated by various processes, and exhibited apart from each other. Water also has been ascertained to be a compound which may be analyzed or decomposed, so as to produce two distinct kinds of gas, which may be separately collected, and when again mixed together in proper proportions, they may be made to form water by their union.

Other bodies, formerly esteemed simple, have yielded to the analytical processes of modern chemistry; but there is a certain number of substances which either in the state in which they are presented to us by nature, or as they are procured in various operations by art, have hitherto resisted all attempts at further decomposition, and which therefore, as before stated, must be regarded as simple substances. Their number is not very great, amounting to about fifty-four, and it is not unlikely that the future researches of chemists may demonstrate some of these bodies to be compounds; at the same time, it is probable that additions may be made to the class of elementary substances in consequence of future discoveries, several of those now admitted into this class having become known to us but very recently.

Some of these elementary bodies are widely and abundantly dispersed throughout the three kingdoms of nature, either alone or in a state of composition, while others appear to be of very rare occurrence, or at least they have hitherto been met with only in small quantities and in a few situations. The whole of the elementary substances may be arranged in two divisions: the first comprehending those which are not of a metallic nature, the entire number of which now known amounts to only thirteen; the remaining forty-one elementary bodies are all regarded as metals, though some of them exhibit properties differing considerably from those which characterize gold, silver, mercury, lead, iron, and other bodies, to which the designation of metals was originally applied.

The following table exhibits a list of all the elementary or simple bodies hitherto discovered, divided into these two classes, namely, the non-metallic elements and the metals; to which are annexed the names of those chemists by whom they were discovered, or by whom their elementary nature was first ascertained, and the date of the discovery.

TABLE OF SIMPLE SUBSTANCES.

I. *Non-metallic Elements.*

		Discoverers.	Date of Discovery.
1	Oxygen . . .	Dr. Priestley, in England; and Scheele, in Sweden	1774
2	Chlorine . . .	Scheele, in Sweden	1774
3	Iodine . . .	Courtois, in France	1811
4	Bromine . . .	Balard, in France	1826
5	Fluorine . .	Properties first accurately investigated by Scheele; but it has never been exhibited in a separate state	
6	Hydrogen . .	Cavendish, in England . . .	1766
7	Nitrogen . .	Dr. D. Rutherford, in Scotland . .	1772
8	Carbon		
9	Boron	Sir H. Davy, in England . .	1807
10	Silicon . . .	Berzelius, in Sweden	1824
11	Phosphorus . .	Brandt, at Hamburgh	1669
12	Sulphur		
13	Selenium . .	Berzelius, in Sweden	1818

II. *Metals.*

14	Potassium . .	Sir H. Davy, in England	1807
15	Sodium . . .		
16	Lithium . .	Oxide discovered by Arfvedson, in Sweden	1818

		Discoverers.	Date of Discovery.
17	Baryum	Sir H. Davy, in England	1808
18	Strontium		
19	Calcium		
20	Magnesium	Bussy, in France	1829
21	Aluminum	Wöhler, in Germany	1828
22	Glucinum	Oxide discovered by Vauquelin, in France	1797
23	Yttrium	Oxide discovered by Gadolin, in Sweden	1794
24	Zirconium	Berzelius, in Sweden	1824
25	Thorium	Berzelius	
26	Cerium	Mosander, in Sweden	1804
27	Tellurium	Klaproth, at Berlin	1797
28	Arsenic	Appears to have been known to Paracelsus, in the 16th century; but first accurately examined by Geo. Brandt, in Sweden	1733
29	Antimony	Known to Basil Valentine	about 1450
30	Chromium	Vauquelin, in France	1797
31	Vanadium	Sefstrom and Berzelius, in Sweden	1830
32	Uranium	Klaproth, at Berlin	1789
33	Molybdenum	Scheele, in Sweden Reduced to the metallic state by Hielm	1778 1782
34	Tungsten	MM. D'Elhuyarts, in Spain	1781
35	Columbium	Oxide discovered by Hatchett, in England; and by Ekeberg, in Sweden Reduced by Berzelius	1801 1824
36	Titanium	Vauquelin, in France	1796
37	Iron		
38	Manganese	Gahn, in Sweden	1774
39	Nickel	Bergman, in Sweden	1775
40	Cobalt	Brandt, in Sweden	1733
41	Zinc	Henckel mentions its reduction in	1721
42	Cadmium	Stromeyer, in Germany	1817
43	Lead		
44	Tin		
45	Copper		

		Discoverers.	Date of Discovery.
46	Bismuth . . .	Mentioned by Geo. Agricola .	about 1530
47	Mercury		
48	Silver		
49	Gold		
50	Platina . . .	Charles Wood, Assay-master in Jamaica	1741
51	Palladium . .	Dr. Wollaston, in England . .	1803
52	Rhodium . .	The same	1804
53	Iridium . . .	Tennant, in England . . .	1803
54	Osmium . . .		

As some of these elementary bodies enter into the composition of a vast variety of substances of common occurrence, and as it is impossible intelligibly to describe chemical phenomena without the frequent mention of them, or allusion to their properties and modes of action, some short notices of them may here be advantageously introduced, previously to a review of the laws of chemical affinity, and a more extensive description of the simple bodies in general, and of the most important compounds arising from their relative action upon each other. We shall thus avoid the necessity of repeated explanations of the nature of these bodies each time they are mentioned, or the still greater inconvenience of referring to the properties and effects of substances with which the reader may be supposed to be unacquainted.

Among the thirteen non-metallic elements there are some which at all common temperatures exist only in the gaseous state, while the others at moderately low temperatures are solids; and among the former are the elementary principles of air, water, and many other bodies around us. The first and most important of the elementary bodies is that called OXYGEN, from two Greek words, denoting the *power of producing acids*, because it was formerly thought to be the universal acidifying principle, though it is now known that there are many acids in which oxygen is not contained. One of the grand characteristic properties of this gaseous element is that of being a most powerful supporter of combustion, so that most inflammable bodies burn in it rapidly and brilliantly. Its more peculiar properties will be subsequently described; and we shall only add here that it unites with all other elementary substances (except possibly fluorine), and with many of them in various proportions.

NITROGEN or AZOTE is also a gaseous body, the mixture of which with oxygen in certain proportions constitutes atmospheric or common air. The name Azote, derived from the Greek, implies its being improper for the purpose of respiration, as animals confined in this gas soon die. It is therefore owing to the oxygen contained in atmospheric air that it is capable of supporting animal life, for none of the higher classes of animals can exist long in any kind of air which does not contain oxygen. The term Nitrogen has been applied to the gas now under notice, in consequence of its being found to be a constituent part of nitric acid, or as it is vulgarly called, aqua fortis, which is a chemical compound containing a very large proportion of oxygen united to the nitrogen. There are also other compounds of oxygen with nitrogen, among which may be mentioned that sometimes called nitrous oxide, and which, though it contains more oxygen than atmospheric air, may yet be breathed for a time with safety; but it produces very remarkable effects when thus used, generally occasioning a state of excitement somewhat similar to that caused by drinking wine or spirits, and hence it has been popularly named intoxicating or laughing gas. Nitrogen enters largely into the composition of most kinds of animal matter.

HYDROGEN is likewise a gas, being that which when combined with oxygen forms water, as its name, which is derived from the Greek, implies. It was, when first discovered, called Phlogiston, and Inflammable Air. The former of these terms was attached to it in consequence of an erroneous opinion, at one period generally adopted by chemists, that all metals were composed of various kinds of calces or earths, each respectively united to an inflammable principle named Phlogiston. Now as it was observed, that when any metal becomes dissolved in a diluted acid, as when iron or zinc are thus treated with sulphuric acid and water, inflammable air was always given off during the process, it was conjectured that the air in question was derived from the metal; though it is now known that, in the case proposed, it arises from the decomposition of the water with which the acid is diluted, and that this sort of air never makes its appearance in the course of such metallic solutions, unless water or some other body containing hydrogen be present. This gas, though highly inflammable when mixed with oxygen, and some other simple and compound gases, yet is *incapable of supporting combustion*, for if a burning body, as a lighted candle or match, be introduced into it, the flame will be immediately extinguished. Hydrogen enters into combination with most other substances, producing many remarkable compounds, among which may be mentioned that formed by its union with nitrogen; the result of which is an alkaline gas, formerly called volatile alkali, and now ammonia. This compound which at common temperatures exists only in the state of gas, is rapidly absorbed by water or spirit of wine, communicating to it a peculiar pungent odour, with which most persons are familiar, as belonging to spirit of hartshorn and smelling salts.

CHLORINE is the last of the simple bodies existing in a gaseous state at common temperatures; but, while those already mentioned are not only transparent but colourless, this gas exhibits a yellowish-green tint, whence its name Chlorine (*Chlore*, in French), from the Greek Χλωρος, which denotes that colour. It was originally obtained, by Scheele, from the decomposition of muriatic acid, or spirit of salt, in which he found it combined with hydrogen, then called Phlogiston; and therefore he gave to the newly-obtained gas the name of Dephlogisticated Marine Acid. It was subsequently supposed to be a compound of muriatic acid and oxygen; but Sir H. Davy ascertained its real nature, and gave it its present name.

Chlorine unites with many other simple and compound bodies, forming with several of them acids; and in other respects it exhibits chemical properties analogous to those of oxygen, being like that gas a *supporter of combustion*. It is largely dispersed throughout nature, but always in a state of combination, as in sea-water and rock-salt, or that procured from brine springs, in which it is united with the metal sodium. This gas is by no means adapted for respiration, and when mixed with much atmospheric air it still proves highly irritating, provoking cough and defluxion from the nostrils. As it combines rapidly with many other gases, it has been found useful to purify air loaded with infectious miasmata. It is on this account that the chloride of lime, in solution, is used to sprinkle the floors and walls of rooms, and to purify clothes and other articles, which have been tainted by putrid or infectious vapours. Chlorine has also a powerful effect in destroying vegetable colours, and the chloride of lime is therefore extensively used in the process of bleaching linen cloth and other substances.

The four preceding bodies, Oxygen, Hydrogen, Nitrogen, and Chlorine, exist at common temperatures and pressures only as gas. There are other substances, as, for instance, Carbon (charcoal), and the more rare bodies, called Silicon and Boron, which are found only in the solid state; and some, like iron and most of the metals, though usually solid, become liquefied at respectively various temperatures; and there is still another class of bodies capable of existing under the three several forms of aggregation. Among these last are Sulphur, Phosphorus, and the substances called Bromine, Iodine, and Selenium, which are of less frequent occurrence.

Carbon is a solid body, hitherto undecomposed, and therefore supposed to be elementary, which enters largely into the composition of most substances belonging to the animal and vegetable kingdoms, and which also forms the basis of many of the combustible minerals, as bitumen, coal, plumbago, and amber. In the form of charcoal, procured by charring, or distilling without the access of air, wood and some other substances, Carbon is obtained in a separate state, or merely intermixed with small portions of earths or salts; and it exists in a state of the greatest purity in the diamond; for it has been ascertained by chemical investigation, that the diamond, when exposed to a very high temperature, and especially if confined in oxygen gas, will burn like charcoal, exhibiting the same product; that gem consisting entirely of crystallized Carbon. With most of the simple substances Carbon constitutes a variety of compounds, among the most important of which are those arising from its union with oxygen, with which it forms both an oxide and an acid: the latter, called Carbonic Acid, is the gaseous body formerly known by the name of fixed air, which is abundantly produced in the combustion of vegetable matter, in the respiration of animals, and in other processes. In consequence of its strong affinity for oxygen, Carbon, or rather substances containing it, are generally used for the purpose of reducing iron and other metals from their ores, in which they are frequently combined with oxygen. The combinations of this body with hydrogen are extremely numerous, forming the bases of vinous spirits, oils, resins, and a great variety of other vegetable products.

Silicon is never met with in nature in an uncombined state, but by its union with oxygen it forms Silica, or siliceous earth, which in the various states of flint, quartz, rock crystal, and other analogous bodies, is dispersed in great abundance throughout the mineral kingdom. This substance when pure is a dark brown powder, which when first discovered was supposed to be of a metallic nature; but as it exhibits none of the lustre of a metal, and is a nonconductor of electricity, it has with propriety been placed in the class of non-metallic elementary bodies. It unites with several other substances, forming compounds, the most important of which, next to the Oxide of Silicon (Silica), is the product of its union with Fluorine.

Boron is the basis of the acid called Boracic Acid, which in combination with Soda or mineral alkali, produces the saline substance named Borax, frequently used both in medicine and the arts. Boron is an olive-brown powder, destitute of taste or smell, which enters into union with some of the metals and other elementary bodies; but its combinations are of little importance, except that which it forms with oxygen (Boracic Acid).

Sulphur is one of the few elementary substances which are found in nature in an uncombined state; and it also often occurs in union with other substances. It is met with in large quantities in the neighbourhood of volcanos; and being produced abundantly in the island of Sicily, it is brought as an article of commerce from the Mediterranean. This substance, hitherto undecomposed, and therefore regarded as elementary, occurs in two forms, that of a light yellow powder called Flowers of Sulphur, and that of a compact solid of a greenish-straw colour, sometimes called Roll Sulphur. The general properties of Sulphur in both these forms are well known. Sulphur combines with most other bodies, forming a variety of compounds; the most remarkable of which are those arising from its union with oxygen and hydrogen. It forms several oxides and acids, and one of the latter, Sulphuric Acid, oil of vitriol of commerce, is much used both alone and in combination, for medical and technical purposes. With hydrogen Sulphur forms a peculiar gas, which has some of the properties of an acid; and which is given off during the putrefaction of animal substances, causing a peculiar offensive smell, resembling that of rotten eggs: it was formerly called Hepatic Air.

Phosphorus, like sulphur, is a solid but readily volatile substance; but is never found in nature in an uncombined state. Some of its compounds occur occasionally in mineral substances; but it is most abundantly contained in certain animal fluids and solids, and especially in bone, from which it is usually obtained for experimental purposes. Phosphorus is found in the shops in the form of small cylinders, semi-transparent, and nearly of the consistence of wax, internally of a reddish or flesh colour, but coated with a white film, arising from its partial decomposition. It so strongly attracts oxygen from the air as to become slowly decomposed at a very low temperature, and hence it is usually kept under water. With oxygen it forms two acids, one of which, the Phosphoric Acid, in combination with lime or calcareous earth, constitutes the basis of bone. It unites with hydrogen, to form an inflammable gas; and it also enters into combination with various other bodies.

Iodine is a bluish-black or violet-coloured solid, having a metallic lustre. It is contained in sea-water, and in some marine productions, as seaweed and sponge; and it is supposed that burnt sponge, which is used in medicine, owes its virtues to the presence of Iodine. This body, like oxygen and chlorine, is not itself combustible, but is a *supporter of combustion*. It unites with various other simple substances; and with oxygen and chlorine, it forms respectively acid compounds.

Bromine, like Iodine, is a marine production, and it is usually procured from the refuse liquor obtained in making sea salt. Its common form is that of a cloudy red liquid, having a very disagreeable smell and taste. It is one of the *supporters of combustion*, and enters into union with various simple bodies, forming acids both with oxygen and chlorine. In many respects, it bears a strong analogy to iodine, and has been supposed to be a compound of that body with chlorine; but there appears to be sufficient evidence of its elementary nature.

Fluorine is generally regarded as an elementary body, though it has never yet been exhibited in a separate state, in consequence of its powerful tendency to form combinations with all known substances. Some of its compounds enter into the composition of certain minerals, among which the best known is that called Fluor Spar, found in Derbyshire; and which, from its beauty and the facility with which it may be cut and polished, is frequently used for making chimney ornaments and other purposes. Among the artificial compounds of fluorine, one of the most important is that which it forms with hydrogen, called Hydro-fluoric Acid, which has the property of corroding glass.

Selenium is a reddish-gray solid, obtained from pyrites, and in many of its properties resembling sulphur, being like that body readily combustible. It has hitherto been found only in a few places, and in small quantities. It forms acids in combination with oxygen; and it also unites with hydrogen and chlorine, and probably with other elementary substances.

Metals.—The metallic elements, as already observed, display great diversity as to their general appearance and properties; and there is, on the other hand, so much similarity between some of these bodies and some of the non-metallic elements, that their distinction becomes difficult and inconsiderable. Hence some chemists have hesitated as to the proper mode of classifying certain substances. Silicon and Selenium have both been regarded as metals; and among the bodies which have been always admitted into the first class, there is not any perhaps which so much resembles the metals as Carbon, in that state of aggregation which constitutes charcoal. Indeed, the elementary or simple substances, metallic and non-metallic, have so many points of analogy as to render it impossible to form a classical arrangement of them, adapted for practical purposes, which may not be liable to objection. In this as well as in other cases, nature seems to display a variety of bodies not capable of being separated into orders or sections, strikingly contrasted with each other, but throughout the whole a gradation appears to take place; whence may be deduced a chain of simple bodies, variously connected with each other: those that in some respects obviously appear to be members of different classes approaching nearly together in certain of their properties and modes of action. However, the usual arrangement of the simple bodies into metals, and those which are not metals, may be conveniently retained, as affording perhaps the most generally applicable method of distinguishing them.

It will be unnecessary to notice separately each of the metallic elements, as we have done those of a non-metallic nature; because several of them are as to their general properties familiarly known, being used either in a state of purity, or combined one with another (forming simple or compound metals), for many common purposes. Thus Iron is the usual material for the construction of a vast multitude of instruments and utensils for domestic and other purposes; Gold, Silver, and Copper, have been long employed in making the coin current in all civilized countries; Lead is used in sheets for covering the roofs of buildings, in tubes for making waterpipes, and on many other occasions; Mercury is well known as remaining fluid at a lower temperature than any other metal, or indeed than almost any other liquid; and it is therefore used in the construction of thermometers and other philosophical instruments. Zinc is often used in combination with other metals, as with Copper in the manufacture of Brass, and it is likewise employed alone, instead of lead, for covering houses; and Tin is not only of general utility for coating other metals, as in making tin plate, but also in its combination with copper forming Bronze or Bell-metal.

Perhaps the metals may be most properly characterized with reference to their power as conductors of electricity, which belongs to all of them in a high degree. This, however, is not an exclusive character of the metallic elements, for Carbon (charcoal) is also a good conductor of electricity, and in this respect it more nearly corresponds with the metals than Silicon or Selenium, which are non-conductors. Among the acknowledged metals there are many which differ greatly from the more common metallic bodies, in being neither malleable nor ductile: such are Antimony, Arsenic, Cobalt, and Manganese. There are others which are distinguished by having a very strong affinity for oxygen; so that at low temperatures they decompose atmospheric air or water, uniting with the oxygen in those bodies to form metallic oxides; as is found to be the case with the metals which Sir H. Davy discovered to be the bases of potash and soda. Therefore when these metals, named Potassium and Sodium, are obtained from the decomposition of their respective oxides, potash and soda, the metals thus formed can only be preserved by keeping them immersed in ether, which does not act on them. Hence it appears that those bodies formerly termed Fixed Alkalies are metallic oxides: and this is also the case with the different earths; thus Calcium is a metal which combined with oxygen forms calcareous earth or lime, a substance which abounds especially in the animal and mineral kingdoms of nature. The earth called Barytes is an oxide of the metal Baryum; Strontites is an oxide of the metal Strontium; Magnesia, in its pure state, commonly called Calcined Magnesia, is an oxide of the metal Magnesium; and Alumine, argillaceous earth or pure clay, is an oxide of the metal Aluminum. The more rare kinds of earths, called Yttria, Glucina, Zircon, and Thorina, are also metallic oxides; and it has been already stated that Silica, pure siliceous earth, is an oxide, though its basis, Silicon, is not a metallic body.

CHEMICAL AFFINITY.

That property of matter which occasions the combination of heterogeneous bodies, is the cause of the principal phenomena of chemistry, and is therefore called Chemical Affinity or Attraction. It is also sometimes termed Elective Attraction, and the Attraction of Composition, to distinguish it from Cohesive or Aggregative Attraction. This interesting subject was first systematically studied in France by M. Geoffroy, who formed a table of elective attractions. Bergmann in Sweden, Kirwan in England, Berthollet in France, and Richter in Germany, afterwards paid particular attention to this branch of science; and the subsequent labours of our countrymen, Dalton and Sir H. Davy, and of the illustrious foreigners, Berzelius, Gay Lussac, Thenard, and others, have made vast additions to our knowledge, concerning this fundamental branch of chemical science.

Chemical Attraction may be defined to be that energy, in consequence of which, different kinds of matter unite to form compounds having properties often dissimilar from those of their component parts, so that the result of chemical combination can only be ascertained, at least in the first instance, by experiment. Thus, if iron filings be dissolved in sulphuric acid, or as it is commonly called, oil of vitriol, a substance will be produced bearing no kind of resemblance to either of its component parts, called by chemists Sulphate of Iron, and vulgarly, Copperas, or green vitriol, which is a greenish, semi-transparent, crystallized substance, having nothing of the appearance of the metal, nor of the sour taste of the acid. Acetic Acid, or the acid of vinegar, in the same manner dissolves copper, and constitutes with it the blue efflorescent salt called Verdigris. Caustic Vegetable Alkali is a deliquescent substance, which, as its name implies, corrodes flesh; and Sulphuric Acid, already mentioned, is a liquid which, when concentrated, acts much in the same manner on flesh, but from the union of these bodies, so destructive to animal matter, results the chemical compound, Sulphate of Potash, a salt which, whether solid or dissolved in water, does not act on the skin, and may be swallowed with safety, being used like the somewhat similar compound, Sulphate of Soda (Glauber salt), for medicinal purposes. Sometimes two liquids or gaseous bodies, by their union, form a solid compound. Thus the gas that rises from Spirit of Hartshorn, called by chemists Ammonia, and Muriatic Acid Gas, if mixed together in an empty jar, become condensed into a white saline solid, called Muriate of Ammonia, or Sal Ammoniac.

The phenomena of Chemical Attraction are regulated by the following laws:

1. This attractive force is exerted in different degrees by different bodies.

2. It operates only on very minute particles of bodies; and hence chemical action is promoted by previous solution, trituration, or other mechanical methods of division and intermixture.

3. When bodies combine, an alteration of temperature generally takes place, sometimes with the exhibition of light.

4. Bodies which have an attraction for each other, are always found to display opposite states of electricity.

5. All bodies are composed of certain atoms or molecules, and chemical combination consists of the union of one or more atoms of one of the uniting bodies, with some determinate number of atoms of the other uniting body.

6. Chemical attraction takes place in three different modes:—(1.) When one simple body is presented to another, for which it has an affinity, a union takes place, and a compound is formed. (2.) If a simple body, A, be presented to a compound, B C, and if A have a stronger affinity for B than C has, the compound B C will be decomposed, and a new compound, A B, will be formed. (3.) If a compound, A B, be presented to another compound, C D, though neither A nor B alone would decompose C D, yet a mutual decomposition may take place between the two compounds, and occasion the formation of two new compounds A D and C B. The first and second modes of attraction are styled instances of simple affinity, or simple elective attraction; and the last mode is styled compound affinity, or compound elective attraction.

7. All compounds, when they enter into union with other bodies without being decomposed, act in the same manner as simple bodies.

These laws of Chemical Attraction may be exemplified and illustrated in the following manner:

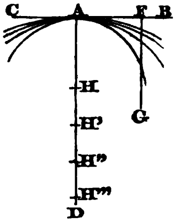
1. The first of these laws constitutes the foundation of the whole science of Chemistry. The ensuing examples show the manner in which it operates.

If thin plates, or filings of copper, be mixed with Sulphuric Acid (oil of vitriol), on the application of heat the metal will be dissolved. The acid thus united to the copper will form a salt, called Sulphate of Copper (blue vitriol), which might be obtained from the solution by evaporation and crystallization. If to this solution be added iron wire, or thin plates of that metal, the sulphuric acid will leave the copper, and combine with the iron. As the latter dissolves, the former, separating from its union with the acid, deposits itself on the iron plates, so that they become covered with a thin film of copper, but when the iron is all dissolved, the copper having nothing to support it, will fall to the bottom of the containing vessel, in a pulverulent form. The clear liquor, being decanted, will therefore be a solution of Sulphate of Iron (green vitriol). If to this solution filings or fragments of zinc be added, the iron will separate by degrees from the liquid and fall down, as the copper previously did, leaving the zinc in solution, forming with the acid, Sulphate of Zinc (white vitriol). If to the solution of Sulphate of Zinc, be added Water of Ammonia (pure volatile alkali), the acid will quit the zinc to unite with the alkali, the metal will be precipitated, and the clear liquor being decanted, will be a solution of Sulphate of Ammonia. Add to this liquor quicklime, which substance will combine with the acid, and separate it from the ammonia, but the new compound of sulphuric acid and lime, thus formed, will not remain in solution, but will be precipitated, or fall down, in the form of a white powder, called Sulphate of Lime (gypsum), while the ammonia, freed from the acid, remains dissolved in the water, from which it may be expelled by heat, in the form of a gas. If the sulphate of lime be separated from the solution by filtering, and thrown into water containing Caustic Potash, a new decomposition will take place, the sulphuric acid leaving the lime, and uniting with the potash. The Sulphate of Potash (vitriolated tartar) thus formed, will remain in solution while the pure lime becomes precipitated in the state of a white powder, and the sulphate of potash may be obtained, in a crystalline form, by evaporating the clear solution, after pouring it from the lime.

This succession of decompositions shows that iron possesses a stronger attraction for sulphuric acid than copper, zinc than iron, ammonia than zinc, lime than ammonia, and potash than lime. Numerous experiments of a similar kind might be adduced, which would equally serve to show the relative attractive powers of various substances. It appears from the preceding experiments, that the decomposition of a substance dissolved in a liquid, is sometimes accompanied by the falling down of the newly formed substance, and sometimes by that of the body separated from the original compound. In this case the body added to produce the decomposition is called the *precipitant*, and the substance thrown down the *precipitate*; the process itself is sometimes termed *precipitation*.

2. The extreme minuteness of the elementary molecules of bodies, from the union of which chemical compounds are formed, appears from the entire change of sensible properties resulting from such combinations. For as already stated, the human eye, assisted by the most powerful microscopes which have ever been constructed, often cannot detect in a chemical compound the slightest vestige of the colour of either of its component parts; but when substances are mechanically mixed, the respective colours of the ingredients of the composition may sometimes be traced, as when variously-tinted powders are triturated together; or if the mixture is more complete, as when two liquids, for instance, ink and water, are shaken together in a phial, though the whole mass will exhibit a uniform appearance, it will be merely a modification of colour, arising from the dilution of the ink by the aqueous fluid.

Some philosophers have ascribed to matter the property of infinite divisibility. But though matter may be conceived to be indefinitely capable of being divided, and though it may even be proved by geometrical demonstration, that a line of a given length may be made to undergo unlimited subdivision, yet there is reason to believe that those bodies with which chemistry is conversant, are formed of indivisible atoms. Matter, then, or rather space, is metaphysically and mathematically, but not physically, capable of being infinitely divided. It is possible to conceive that a cubic inch may be separated into 10,000 smaller cubes, and each of the latter into as many millions of millions of minuter parts of a similar shape, nor can there be any limit to such subdivision, which must be as extensive as the power of enumeration. The mathematical demonstration of the infinite divisibility of matter is founded on the impossibility of conceiving any limits to absolute space. Let A D and F G, in the marginal figure, be two lines parallel with each other, and perpendicular to the line B C; then from the points H, H′, H″, H‴, as centres, describe so many arcs of circles, cutting the lines F G, and A D; and since the line A D may be imagined to be as extensive as space itself, it is impossible to prescribe bounds to the number of points which may be made the centres of circular arcs, and as the number of arcs is boundless, so will be the number of parts into which they will divide the line F G; for the arc, how immense soever might be the length of its radius, could not possibly become coincident with the right line B C.



These observations are worthy of attention, as they may serve to assist us in forming distinct conceptions concerning the wonderful minuteness of the particles of matter, considered in a physical point of view. Among the numerous instances that might be produced of the minute division of material bodies, may be mentioned the extreme diffusion of colouring particles through a transparent fluid. A grain of carmine rubbed down with a little water, and then mixed with six quarts more, will give the whole liquid a pale red or flesh colour; and one grain of blue vitriol (sulphate of copper), will communicate a fine azure tint to five gallons of water. Boyle says, that a pair of Spanish gloves, which had been scented by a single grain of musk, retained their odour for twenty-nine years. The same philosopher placed a piece of amber weighing 100 grains in the scale of a balance, which turned with a small fraction of a grain, and having counterpoised it, he left it for several days, at the end of which time it had lost no perceptible portion of its weight, though it had been continually giving off particles, which had perfumed the surrounding air.*

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* De Mira Subtil. Effluv. Sigaud de la Fond. Elém. de Phys., t. i. pp. 156 et 160.

Malleable and ductile metals are capable of being reduced to a most extraordinary degree of tenuity. Gold, after being submitted to the operations of the goldbeater, is formed into leaves 3.3 inches square, each weighing rather less than the fifth part of a grain, and being but the 282,000th part of an inch in thickness; and a particle of this gold leaf not exceeding the 500,000th of a grain will be distinctly visible to the naked eye.* Still more comminuted doubtless are the particles of gold left in the abrasion of a gold pin on a touchstone, but yet perfectly perceptible to the sight. Bubbles of soap and water consist of films far more attenuated than leaf gold, for when they begin to reflect colours, their thickness is less than 2,000,000ths of an inch, and that must be much beyond the diameter of the atoms of water; for the film contains soap incorporated with the water, and we cannot even conjecture what relation the dimensions of the atoms of the fluid may bear to those of the film which it forms, only they must be far inferior. Besides both soap and water are compounds, so that the constituent atoms of those substances, as of the oxygen and hydrogen of the water, must be yet more reduced, till they almost surpass the power of imagination.

The vegetable kingdom presents us with innumerable instances, not only of the extraordinary divisibility of matter, but of its activity, in the almost incredibly rapid development of cellular structure in certain plants. Thus the *Bovista giganteum* (a species of fungus), has been known to acquire the size of a gourd in one night. Now supposing, with Professor Lindley, that the cellules of this plant are not less than $\frac{1}{200}$th of an inch in diameter, a plant of the above size will contain no less than 47,000,000,000 cellules; so that supposing it to have grown in the course of twelve hours, its cellules must have been developed at the rate of nearly 4,000,000,000 per hour, or of more than 66,000,000 in a minute; and when we consider that every one of these cellules must be composed of innumerable molecules, each one of which is again composed of others, we are perfectly overwhelmed with the minuteness and number of the parts employed in this single production of nature.†

The animal world affords examples of the incomprehensible divisibility of matter not less wonderful. Mr. Harmer by counting the number of ova in a given weight of the spawn of different fishes, found that a single flounder contained 1,357,400; and a cod-fish no less than 3,686,760 ova; all of which, it must be remembered, were organized bodies, capable of development, so as to form perfect animals.[*] But the infusory animalcules display, in their structure and functions, the most transcendent attenuation of matter. The *Vibrio undula*, found in duckweed, is computed to be ten thousand million times smaller than a hemp-seed. *Vibrio lineola* occurs in vegetable infusions, every drop containing myriads of those oblong points. The *Monas gelatinosa*, discovered in ditch-water, appears in the field of a microscope a mere atom endued with life, millions of them playing like the sunbeams, in a single drop of liquid.[†]

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* Leslie's Elem. of Nat. Philos., vol. i. p. 13.

† Dr. Prout's Chemistry, Meteorology, and the Function of Digestion considered with reference to Natural Theology, 1834, pp. 23, 24; from Lindley's Introduction to Botany.

That all bodies are composed of atoms or ultimate indivisible particles, may be inferred from the observations which have been made on the height of the atmosphere above the surface of the earth. Dr. Wollaston adduced some ingenious arguments in proof of the limited extent of the aërial medium which surrounds the globe, as resulting from its atomic constitution.[‡] And if we admit that such is the nature of the air, it may also be concluded that bodies of greater density consist in the same manner of indivisible molecules.

The instances already mentioned of the extraordinary minuteness of particles of matter relate to bodies which are manifestly compounds, and the magnitude of such particles must therefore be far superior to that of the ultimate or even the constituent molecules of those bodies. With regard to the bulk or weight of absolute atoms, or ultimate molecules of matter, we can form no conceptions whatever, and their nature and properties must probably remain objects of conjecture and uncertainty; but the constituent or combining molecules of different substances are more within the reach of experiment and observation, and concerning their relative magnitudes or proportional weights the researches of modern philosophers furnish us with some information. Dr. Thomson has calculated that the weight of a constituent molecule of lead does not exceed $\frac{1}{310,000,000,000}$th of a grain, and that its magnitude is probably much less than $\frac{1}{888,492,000,000,000}$th of a cubic inch. The combining molecules of sulphur are vastly inferior to those of lead, each being computed to be not more than $\frac{1}{2,015,000,000,000}$th of a grain; and the molecules of some other bodies are undoubtedly much more diminutive.*

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[*] Philosoph. Transact., vol. lvii. 1767, art. 30.

[†] Leslie's Nat. Philos., vol. i. p. 16.

[‡] See Book of Science, part i. 1st edit. p. 209. 2d edit. p. 215.

3. The change of temperature that results from chemical combination is sometimes very considerable. Thus the burning of charcoal is a combination of charcoal or carbon with the oxygen of the atmosphere, and the consequent production of carbonic acid. Abundance of heat is evolved in this process, which has been supposed to be derived from the oxygen gas consumed. Much heat is also given out when nitrous acid or aqua fortis is mixed with oil of amber; those fluids uniting to form a resinous substance, which from its peculiar odour has obtained the name of artificial musk. The elevation or depression of temperature which accompanies the formation of chemical compounds has given rise to various hypotheses, among which the most plausible, perhaps, is that which deduces the heat or cold manifested in such cases from the change of state in the elements of the combining bodies, or the relation of their respective capacities for heat with that of the compound. Thus it has been imagined, that when the specific heat of a compound is less than that of the bodies from whose union it is formed, the superabundant heat will be given out and become sensible; and if the specific heat of the compound be greater than that of its component parts, it must absorb heat from surrounding bodies, and thus occasion a sensible depression of temperature. But this view of the cause of the changes of temperature that take place is hardly consistent with the conclusions derived from the latest researches of philosophers concerning the specific heat of different bodies, and especially of gases; and the relation of chemical attraction to heat is a subject which still remains open for future investigation.

A few observations may, however, be added concerning two important topics connected with this law of chemical affinity, namely, Combustion, and the Solution of Solids in Liquids.

The term Combustion has been variously applied by different writers; some extending it to all cases of violent chemical action, accompanied by the evolution of light and heat; and others restricting it to certain processes in which combustible bodies more or less rapidly combine with oxygen, with the extrication of light and heat, as in the burning of charcoal, noticed above. Lavoisier, who was the first in modern times that clearly ascertained the influence of atmospheric air on chemical operations, and showed that the changes which bodies undergo frequently depend on the absorption of oxygen, was led to conclude that all simple substances might be arranged in two classes; the first comprising oxygen only, which he characterized as a supporter of combustion; and the second, consisting of combustible bodies, including the metals. Hence he further inferred, that oxygen gas consisted of a ponderable basis, combined with light and heat; which were given out in the form of flame during combustion or the union of combustible bodies, as carbon, sulphur, phosphorus, oil, and alcohol, with the basis of oxygen gas. But this theory, though to a certain extent it may be admitted, is by no means applicable to all cases of combustion in which oxygen gas or atmospheric air is present, and it is necessarily incapable of affording an explanation of those instances of the evolution of light and heat consequent on the sudden union of bodies which contain no oxygen whatever. Thus if equal volumes of chlorine gas and hydrogen gas be introduced into a glass jar, and exposed to the direct rays of the sun, they rapidly combine, with explosion, or the display of abundance of light and heat. Phosphorus burns with a pale yellow flame, when heated in chlorine gas; and when phosphorus is introduced into an exhausted vessel with iodine, a violent action takes place, and much heat is extricated, but without light. If sulphur and filings of copper be heated together, when the mixture has acquired a temperature much below a red heat, it suddenly becomes red-hot, and the compound called sulphuret of copper is formed. Many other examples might be adduced of the production of heat either alone or accompanied by light, during chemical combinations. in which oxygen is not at all concerned. Unless, therefore, the term Combustion be exclusively appropriated to the process of burning combustibles in atmospheric air or some other aërial medium in which oxygen is contained, the phenomena with which the process is accompanied cannot possibly be said to be caused by the condensation of oxygen gas; and in the present state of our knowledge, any attempt to develope their source may be considered as somewhat premature.

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* Thomson's Principles of Inorganic Chemistry, vol. i. p. 7.

Combustion, as depending on the union of oxygen with a combustible body, sometimes takes place under singular circumstances, and gives rise to extraordinary appearances. The temperatures at which different combustibles combine with oxygen vary extremely. Potassium, or the metallic body which in combination with oxygen forms potash or fixed vegetable alkali, most powerfully attracts oxygen, tarnishing when exposed to the air at a very low temperature, and becoming inflamed when thrown into cold water, potash being formed in either case. Phosphorus, when quite dry, takes fire in atmospheric air, at about 100° of Fahrenheit. Sulphur burns in common air at from 180° to 190°, but with a faint blue flame, the heat of which is very inconsiderable; but if its temperature be raised to 300°, the combustion proceeds more rapidly. Carbon, in the state of common charcoal, demands a higher temperature for its combustion than the substances already mentioned; and in its crystallized form, in the diamond, it requires an intense heat, as the flame of an oxy-hydrogen blowpipe, to set it on fire. When highly comminuted, however, charcoal, and especially some varieties of it, attract oxygen, exhibiting the phenomena of combustion at relatively low temperatures; and hence, in certain cases, what is termed spontaneous inflammation has taken place. Colonel Aubert, an artillery officer, in consequence of repeated instances of the spontaneous combustion of powdered charcoal which had occurred in France, made some interesting experiments on the subject. He found that charcoal triturated in mortars with bronze pestles, till it is reduced to the finest powder, has the appearance of an oily fluid, and occupies only one-third of the space which it takes up when in the form of rods about six inches in length. In this state of extreme division it absorbs air much more readily than before; but the absorption proceeds slowly, requiring several days for its completion, and it is accompanied by the evolution of heat sufficient to raise the thermometer to about 360° of Fahrenheit, and thus inflammation is occasioned. The process commences near the centre of the mass, about five or six inches from its surface, at which spot the temperature is always higher than at any other. Black charcoal, strongly distilled, is more readily inflammable than lighter varieties. Masses of this kind of charcoal, less than 66 pounds avoirdupois, do not inflame spontaneously; and the other kinds inflame only when in larger masses. The free admission of air to the surface is indispensably requisite to produce spontaneous combustion. When sulphur and nitre are added to the pulverized charcoal, the inflammation does not take place as usual; but there is still some absorption of air, and augmentation of temperature; therefore it would be dangerous to leave large quantities of such mixtures long exposed to the air.*

The spontaneous combustion of substances containing carbon, from the absorption of air and moisture is a phenomenon of so frequent occurrence that few persons can be ignorant of it, though those who are unacquainted with chemistry must be at a loss to account for it. Ricks of hay and stacks of corn thus occasionally take fire, and are consumed; and repeated narratives have been published of the destruction of packages of coffee, bales of cotton and other articles, in consequence of spontaneous inflammation. Much appears to depend in these cases on the presence of water; for hay-ricks take fire only when the hay is put together before it is properly dried, or in consequence of its not being well secured from the rain. An instance of the spontaneous combustion of a quantity of oatmeal, which had been left in the house of a gentleman at Glasgow, during the absence of his family from home from May till the end of August, in 1820, is mentioned in Dr. Thomson's "Annals of Philosophy;" and the accident is justly attributed to the avidity with which oatmeal attracts moisture, a property that induced Professor Leslie to employ it instead of sulphuric acid, in his ingenious process for the production of ice under the exhausted receiver of an air-pump.†

Spontaneous combustion sometimes takes place very suddenly. Dr. Bache, of Philadelphia, discovered that carbon in the state of lampblack, or the soot of animal oil, causes the inflammation of a stick of phosphorus powdered with it, at the temperature of 60° of Fahrenheit, either in the open air, or in a close receiver of a moderate size.‡

Professor Döbereiner, of Jena, discovered a curious phenomenon of an analogous nature relative to spontaneous combustion in 1823. He found that platina, in the state of very fine wire, thin leaves, powder, or in the spongy form, at the common temperature of the air, if plunged into a mixture of hydrogen gas and atmospheric air, would almost instantly take fire. The platina becomes heated, presently red-hot, then it attains a white heat, and immediately the hydrogen inflames, and the combustion continues as long as any portion of the combustible elements remains. Brewster says, "In this case the minutely-divided platina acted upon the hydrogen gas in the same manner as the minutely-divided charcoal acted upon common air. Heat and combustion were produced by the absorption of both gases, though in the one case the effect was instantaneous, and in the other was the result of a prolonged absorption."*

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* See Ann. de Chim.; and Edinb. Journ. of Science, N. S. No. 8.

† See Journ. of Science, ed. at R. I., vol. x. p. 454; and Ann. of Philos., vol. xvi. p. 390.

‡ Silliman's Journ. of Science.

This property of spongy platina has been happily applied to a purpose of much practical utility, by M. Gay Lussac, in the contrivance of a lamp for the production of instantaneous light. Improvements or modifications of this instrument have been made by Mr. Garden and others; but the principle on which the apparatus is constructed is the same in all, and they consist of arrangements for the regulated production of hydrogen gas, from the solution of zinc or iron in diluted sulphuric acid, and by opening a stop-cock throwing a current of the gas on a mass of spongy platina, which becoming red-hot, the hydrogen inflames, and affords the means for lighting a taper.

Numerous experiments were made by MM. Dulong and Thenard, with a view to elucidate the cause of the inflammation produced by the contact of finely-divided platina with hydrogen gas. From their researches it appeared—1. That palladium, rhodium, and iridium, have the same effect on the gas with platina; 2. That osmium in like manner produces inflammation, but requires a temperature of 45° centigrade, and gold inflames at 120°; 3. That charcoal, glass, pumice-stone, and porcelain, have similar effects, but at temperatures near 250°; 4. That all these bodies lose the property in question by long exposure to the air, but they recover it on being calcined.†

Among the various causes of spontaneous combustion that might be mentioned, there is none more interesting or curious than that of the human body, many instances of which are upon record. But the subject will again be noticed, in treating of the effect of electricity on chemical attraction, and therefore need not be introduced here.

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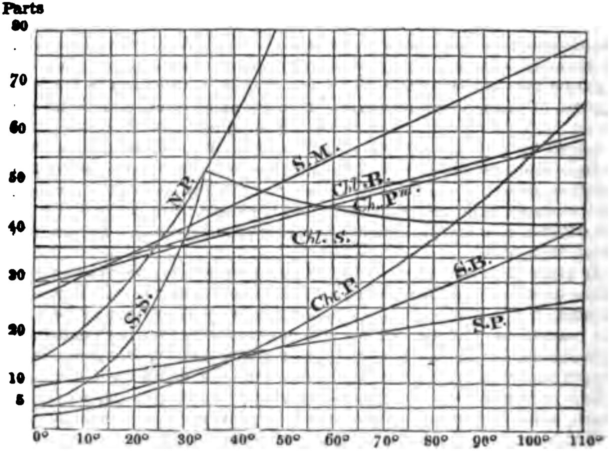
* Sir D. Brewster's Natural Magic, p. 318.

† Pouillet Elém. de Phys., vol. i. pp. 425, 426.

Elevation of temperature generally promotes the chemical action of bodies. Its influence in many cases appears to depend on the diminution of cohesion, or the separation of the particles of matter by heat, as when expansion or liquefaction takes place. But its effects are sometimes more complicated and obscure; and the phenomena indicate an obvious correspondence between heat and electricity or galvanism. A remarkable instance of the influence of heat, in conjunction with light on the chemical union of bodies, may be pointed out in the production of muriatic acid from the mixture of chlorine and hydrogen gases, noticed above. When the proper quantities of these gases required to form the compound are mingled in a glass jar, so long as light and heat are excluded, no combination takes place, but if the mixture be exposed to the direct rays of the sun, detonation ensues, and muriatic acid gas is formed; and the same effect is produced by introducing into the jar a lighted taper, or passing through its contents an electric spark.

It must be observed that though elevation of temperature to a certain extent may facilitate the chemical union of bodies, the effect will depend, in any given case, on the adaptation of the degree of heat to the particular process. Thus mercury exposed to the contact of atmospheric air at the temperature of nearly 680° Fahrenheit, in a proper vessel, combines with oxygen to form the red oxide of mercury, which substance, when exposed to a red heat, 980°, becomes decomposed, returning to the state of metallic mercury and oxygen gas.

Temperature has generally a great influence on the solvent power of water, and also on that of other liquids. Hot water is capable of holding in solution larger quantities of most substances than cold water: thus, saltpetre, or nitrate of potash, and chlorate of potash, are much more readily soluble in water at a high than at a low temperature; and with regard to many other saline bodies the dissolving power of the liquid is increased by augmentation of temperature. But this is by no means always the case. Water cooled to near the freezing point, will take up almost double the quantity of caustic lime that can be held in solution by boiling water. Glauber salt, or sulphate of soda, is most readily soluble in water at about 92° Fahrenheit (33° cent.), the solvent power of water with respect to that salt increasing with the augmentation of heat up to that point, after which it diminishes to 215°, at which temperature nearly the same relative quantity of the salt will be taken up as at 87°. Seleniate of soda likewise is more soluble at 92° (33° Cent.) than at a higher or lower temperature.



N. P. Nitrate of Potash.
S. M. Sulphate of Magnesia (anhydrous).
S. S. Sulphate of Soda (anhydrous).
Chl. B. Chloride of Baryum (anhydrous).
Ch. Pm. Chloride of Potassium.
Chl. S. Chloride of Sodium.
Cht. P. Chlorate of Potash.
S. B. Sulphate of Barytes.
S. P. Sulphate of Potash.

The relation between temperature and solubility will be most distinctly perceived from the inspection of the preceding table. The vertical line of figures indicates the respective portions of several salts, taken up by 100 parts of water, and the horizontal line of figures denotes the temperatures at which these solutions take place. The line which is marked Chl. S., shows the solubility of Chloride of Sodium (common salt), and it cuts the perpendicular lines all at the same height, No. 37, which indicates that 100 parts of water will at all temperatures dissolve 37 parts of common salt. The line marked Chl. B., anhydrous chloride of baryum, cuts the perpendicular line marked 0° at No. 31, that which is marked 55° at No. 45, and that marked 110° at No. 61: hence it must be understood that 100 parts of water will take up 31 parts of anhydrous chloride of baryum at zero, 45 parts at 55°, and 61 parts at 110°. The line marked S. S., sulphate of soda, rises to 33°, and then descends, denoting the sulphate to be most soluble at that temperature, as above stated. The manner in which the various influence of temperature on other salts is exhibited in this table, will be sufficiently obvious from the preceding examples.*

4. The influence of electricity on chemical processes, attracted the attention of philosophers before the middle of the last century, when it was ascertained that ether might be fired by the electric spark; and the deflagration of spirit of wine, fulminating gold, and some other inflammable bodies, was soon after effected by the same means. More recent researches evinced the possibility of producing the combustion of iron wire by exposing it to the shock of an electric battery. The metal is thus oxidated in the same manner as by the violent friction caused by striking fire with a flint and steel. Other metals, as well as iron, may be made to undergo combustion, by exposing them to the charge of a battery of electric jars. A fine gold wire may thus be burnt, yielding a bluish-white flame, and the product will be a protoxide of gold, in the state of an impalpable purple powder. Silver wire may in the same manner be made to burn with a green flame; and corresponding phenomena take place with the other metals. The effect of the electricity of excited jars on the combination of gases, was the subject of experiments by Mr. Warltire, Dr. Priestley, and Mr. Cavendish; and the latter, about 1776, thus

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* This table is taken from Mitscherlich's Introduction to Chemistry (Germ.), Berlin, 1832, 8vo, vol. i. p. 267. The temperatures are given according to the scale of the centigrade thermometer.

produced water, by firing a mixture of hydrogen gas and atmospheric air; and he also obtained nitric acid, by employing electricity to determine the combination of oxygen and nitrogen. In 1781, Lavoisier and Laplace made important experiments on the development of electricity in the evaporation of liquids, and the solution of solids, as when metals are dissolved in diluted acids; and from the later researches of Becquerel, at Paris, it may be concluded that electricity is evolved in all cases of chemical solution.

The relation between electrical and chemical attraction has been confirmed by the discovery of Galvanic or Voltaic electricity, the effects of which manifestly depend on the same peculiar energy that gives rise to the phenomena of the Leyden phial. It has been ascertained that chemical decompositions and combinations can be accomplished more easily and readily by means of the Voltaic pile or battery, than by the aid of an electrical machine and the apparatus belonging to it.

Some notice has been taken of the chemical power of the Voltaic battery in the preceding volume of this work, to which the reader is referred for an account of the construction of Galvanic or Voltaic troughs, for the reception of zinc and copper plates with an interposed fluid, which may be used for the production of various chemical phenomena.* With such a Voltaic battery, water and other chemical compounds in a fluid state may be decomposed, merely by dipping the extremities of two wires communicating with the opposite poles of the battery beneath the surface of the mass of fluid, and thus causing the latter to form part of a Voltaic circle. The decomposition of a saline substance, as sulphate of soda, may be thus effected, by using a glass tube bent so that the angular part may fit into a common wine-glass, which will serve to support it. Then into the open ends of the tube insert two wires or strips of platina foil, which may reach nearly to the angle, but must not come in contact; fill the tube with a solution of the sulphate, and connect one of the wires with the zinc or negative pole, and the other with the copper or positive pole, of a Voltaic battery, and the salt will be decomposed, the alkali or soda collecting in the leg of the inverted siphon or tube in connexion with the negative pole, and the sulphuric acid in the part of the tube connected with the positive pole.

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* See Book of Science, pt. i. pp. 450, 451, 454; 2d edit. pp. 465, 466, 471.

In all cases of decomposition by means of electricity, whether derived from the friction of glass, as by the common machine, or from the contact of perfect and imperfect conductors, as in the Voltaic battery, it will be found that one of the constituent elements of the body undergoing decomposition will be evolved at the negative pole, and the other at the positive. Hence it must be concluded, that the bodies thus separating must, with respect to each other, be actuated by opposite kinds of electricity; and the observation of this phenomenon has led to an arrangement of bodies in two classes, namely, electro-negative and electro-positive substances: all those kinds of matter which are attracted by the positive pole of a Galvanic battery being included in the former class, and all those attracted by the negative pole in the latter class. From the application of this principle to the simple or elementary bodies it will follow that oxygen, chlorine, iodine, bromine, and fluorine, are electro-negative bodies; and hydrogen, nitrogen, carbon, boron, silicon, phosphorus, sulphur, selenium, and the metals, are all electro-positive bodies. Thus it will be found that when any compound, formed by the union of either of the five electro-negative elements with any one of the electro-positive class, is submitted to the action of a Voltaic battery, the separation of its constituent principles will be effected in such a manner that the electro-negative matter may be evolved at the wire communicating with the positive pole of the battery, and the electro-positive matter at the negative wire. If, however, the wire be formed of a metal capable of combining with the evolved element, the latter, instead of appearing in a separate form, will unite with the metallic wire, forming a new compound. Such an arrangement takes place when water is decomposed by a Voltaic battery, with iron wires passing from its opposite poles; for if the ends of the wires be dipped into a glass of water, the positive wire or that at which the oxygen ought to be given off will become oxidated, and the hydrogen or electro-positive element will appear in the gaseous state at the negative wire; so that if a tube, closed at one end and filled with water, be inverted over the extremity of that wire, the hydrogen gas may be collected in it.

But though the distinction between the electro-negative and the electro-positive bodies is sufficiently obvious in the decomposition of compounds of two bodies of the opposite classes, yet it requires modification when applied to compounds resulting from the union of two electro-negative or two electro-positive bodies respectively. Oxygen, when separated from its combinations with other simple bodies by electricity, is always evolved at the positive pole; and it may therefore be concluded that it is the most electro-negative of all known substances. It forms compounds with chlorine and the other electro-negative elements, constituting the chloric, iodic, and bromic acids; and when these are decomposed by the Voltaic battery, the oxygen is evolved at the positive pole, and the chlorine, iodine, or bromine, at the negative pole. In the same manner the electro-positive elements enter into union with each other, forming compounds which, when electrically decomposed, manifestly indicate gradations of electric energy among them. Sulphur, which, with respect to oxygen, chlorine, iodine, and bromine, and probably some other simple bodies, is electro-positive, becomes electro-negative when combined with hydrogen; for when a compound of sulphur and hydrogen is decomposed by Voltaic electricity, the sulphur appears at the positive pole, and the hydrogen at the negative. The sulphurets of carbon, phosphorus, and many, if not all the metals, exhibit similar phenomena. Hence it appears, that sulphur is only relatively electro-positive, as in its combinations with oxygen, while it becomes electro-negative by being united to hydrogen, carbon, phosphorus, and the metals.* Experiments are wanting to enable us to ascertain how far the electricity of all bodies is merely relative, or whether the disposition of bodies to be attracted by the positive pole of a Voltaic pile or battery, which seems to exist in the strongest degree in oxygen, descends by a regular gradation throughout the catalogue of simple substances. We may remark, however, that while those which have been designated electro-negative bodies display the highest electro-chemical energy, or tendency to be attracted from their compounds by the positively electrified wire, hydrogen and some of the metals seem to have in an extreme degree the contrary disposition to be attracted by the negative wire.

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* For some interesting and curious observations on the electro-chemical properties of sulphur, see "Report on the Recent Progress and Present State of Chemical Science. By James F. W. Johnston, A. M." Reports of the British Association for the Advancement of Science, 1832, pp. 440—442.

The influence of electric attraction on the chemical affinities of bodies is especially observable in the combination of metals with oxygen, and in the decomposition of metallic salts. Pure potash or vegetable alkali is a compound of oxygen with the metal called potassium; and the affinity between those bodies is so strong, that chemists were long baffled in their attempts to effect their decomposition. At length Sir H. Davy succeeded, by exposing moistened potash to the action of a Voltaic battery; thus augmenting the respective electro-chemical energies of the oxygen and the metal, they were severally attracted by the wires connected with the opposite poles, and the former was evolved at the positive, while the latter (the metallic potassium) made its appearance at the negative pole.

Some other curious and interesting phenomena, relating to the affinities between metals and acids may here be noticed, as tending to illustrate the influence of electricity on the chemical union of bodies. Metals may be immersed in liquid acids, which under common circumstances reduce them to the state of oxides, but the action of such acids may be suspended by rendering the metal electro-negative, or placing it in communication with the negative pole of a Voltaic battery. If two polished plates of iron or copper be plunged in diluted sulphuric acid, one of the plates of either metal having been previously connected with the positive wire of a Voltaic battery, and the other plate of the metal connected with the negative wire, it will presently be perceived that the plate rendered positive will become tarnished and corroded by the action of the acid, while it will take no effect on the negative plate, which will remain as bright as before immersion. Silver unprotected is readily acted on by diluted nitric acid, which dissolves the metal placed in contact with it, just as sulphuric acid dissolves iron; but if the silver be rendered electro-negative, it is enabled to resist the power of the acid, even when long immersed in it.

As electricity is evolved by the contact of different metals with water and other fluids, hence it sometimes happens that two metals connected together and plunged in an acid or saline liquid, may form a kind of miniature Voltaic apparatus, and the common effect of the menstruum is augmented with respect to one of the metals, and controlled or suspended with respect to the other. Let a small piece of sheet copper be dropped into a tumbler-glass, containing two drams of nitric acid diluted with ten drams of water, and in a short time enough of the metal will be dissolved to give a bluish tint to the liquid: the addition of a few drops of liquor of ammonia will increase considerably the depth of the colour, and render it more perceptible. Now, if a plate of copper united to one of zinc be immersed in an acid mixture of the same kind, it will not act at all on the copper, but will more rapidly dissolve the zinc than if that metal were plunged in it alone. That the copper in this case is protected by the zinc from the action of the acid menstruum, will appear on dropping into it liquor of ammonia, as before; for it will now produce no effect, since though that alkali communicates a blue or purple colour to solutions of copper, no such change takes place on adding it to those of zinc. Iron may thus be shielded from the dissolving power of acids, as will appear by immersing a polished plate of that metal, with one of zinc attached to it, in any weak acid, as the muriatic (spirit of salt), largely diluted with water; for while the zinc will undergo solution, the plate of iron will remain bright and untarnished, though if plunged in the diluted acid alone, it would be acted upon immediately.

On the observation of the electro-chemical effects of the contact of metals was founded a method, proposed by Sir H. Davy, for preserving the copper sheathing of ships from the corroding action of sea-water. It has long been the custom among ship-builders to cover the outer surface of the hulls of large vessels with sheets of copper, the durability and consequent advantages of which were found to be greatly diminished by the action of the saline matters contained in sea-water on the metal, producing oxidation, corrosion, and decay. The plan proposed for the prevention of these injurious effects of the exposure of the copper sheathing of ships to the action of sea-water during long voyages, consisted in fixing to the surface of the copper plates of zinc or iron, called protectors, the effect of which was to render the copper electro-negative, and thus prevent it from attracting oxygen from the water, or substances held in solution in it; the protectors themselves becoming oxidated and gradually dissolved, while the copper was preserved. Experiments conducted on a small scale, and for a very limited period, showed that the effect intended might certainly be produced. But it was found that when a copper-bottomed vessel was armed with Davy's protectors, though the copper in the course of a long voyage was prevented by its electro-negative energy from becoming oxidized, yet from the same cause it powerfully attracted from the sea-water earthy matter, such as lime, magnesia, and other electro-positive bodies dissolved in it, and thus acquired a rough coating to which marine plants and animals became attached so abundantly as to prove a serious inconvenience. The failure of this plan, under such circumstances, only serves more strikingly to illustrate the principle under consideration.

In the whole range of experimental chemistry there are few phenomena more curious or beautiful than those exhibited by metallic arborizations, or the depositions of crystallized metals, from the decomposition of metallic salts. An attention to the manner in which such experiments are conducted will enable us to trace a strong analogy between these processes, and some of the instances of electro-chemical decomposition previously adduced.

The production of the Tree of Diana (*Arbor Dianæ*), a process said to have been invented by Lemery, a French chemist, in the beginning of the last century, must have excited the admiration of many persons quite unacquainted with chemistry. To form this crystallization, let six drams of a saturated solution of pure silver in nitric acid, and four drams of a similar solution of mercury in the same acid, be diluted with five ounces of distilled water, and poured into a small decanter or glass phial; then compose an amalgam, by mixing one part of finely-divided silver with seven parts of mercury, and place a small lump of it at the bottom of the bottle, which must be kept quite still. In a short time the surface of the amalgam will be covered with minute filaments of silver, and after standing about forty-eight hours, the solution will deposit all its silver, in the form of brilliant, arborescent crystals, springing like a glittering shrub from the bottom of the vessel.*

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* Mr. Brande says, "The principal use of the addition of mercury to the solution, and of silver to the precipitating mercury, is to give a degree of tenacity to the arborescent deposit of crystals, which prevents their falling to the bottom of the flask."—*Manual of Chemistry*, 3d edit. 1830, vol. ii. p. 184. It seems difficult, however, to conceive how the mercury that remains in solution, or the divided silver in the amalgam, can communicate tenacity to the crystalline deposit; and though the silver in the amalgam may serve as a sort of nucleus for the newly-formed metal, yet it is most probable that the nitrate of mercury and the metallic silver contribute to the success of the experiment chiefly by forming a Voltaic circle, or combination of electro-

An experiment of a very similar nature, which requires less skill and attention in its management than the preceding, is the reduction of lead in the crystalline state from its combination with acetic acid, by means of zinc. This may be effected simply by suspending a lump of zinc in a solution of acetate of lead, commonly called sugar of lead, in the proportion of two drams of the salt to six ounces of water, contained in a glass phial or flask. In this case the revived metal is deposited more slowly, forming shining foliated crystals, first covering the surface of the zinc and then extending from it towards the bottom of the phial. Here the electro-positive zinc attracts oxygen from the relatively electro-negative lead, and forms acetate of zinc, while the lead is set free.

The decomposition of metallic salts may be effected by means of electro-positive bodies not of a metallic nature, giving rise to appearances much resembling those already described. If a lump of charcoal be suspended in a solution of sulphate of copper, the metal will be gradually revived, forming small crystals on the surface of the charcoal. And a stick of phosphorus immersed in a solution of nitrate of silver will become covered with a crystalline incrustation of the reduced metal.

The following method of forming metallic arborizations on the surface of glass, so as to produce a pleasing effect, was published a few years ago in a French journal. Place a few filings of copper and of iron on a glass plate, at a certain distance one from the other. Then drop a little nitrate of silver (in solution) on each parcel: the silver will soon begin to be precipitated, while the iron and copper are oxidized and become coloured. Now with a small and pointed stick the metallic ramifications may be arranged in any figures, and the flame of a taper held under the plate will promote the evaporation of the liquid, facilitate the mutual action of the metals, and by blackening the under side of the plate, form a sort of ground for the design traced out.*

In this and many other processes of a corresponding character, the

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positive and electro-negative bodies, in consequence of which the electro-positive metal, mercury, is enabled the more easily to decompose the nitrate of silver.

* Journal of Science, ed. at R. Inst., vol. x. p. 181; from "Annales de Chimie."

effects may with probability be attributed to the contrast of the electro-positive and electro-negative energies of the bodies brought within the sphere of each other's action. And though many topics of research with regard to electro-chemistry remain for investigation, it may be concluded from what is already known, that bodies attracting each other to form chemical compounds will always exhibit opposite states of electricity, and compounds may be decomposed or combinations prevented by altering the relative electricities of the bodies whose union is thus interrupted.

Some writers have considered electricity as the general cause of combustion; and the recent discoveries of philosophers relative to the intimate connexion between electricity, magnetism, and heat,* afford grounds for concluding that the peculiar energy which gives rise to electric phenomena, may extend its influence to all cases of chemical combination, and especially to those which are accompanied by the extrication of light and heat.† In illustrating the third law of chemical affinity, or that which relates to the influence of temperature, examples have been given of cases of spontaneous combustion, which are traced to the evolution of heat, in consequence of the absorption of atmospheric air, or the oxygenous portion of it, by large masses of combustible matter.‡ That electricity is concerned in the production of these phenomena is at least highly probable, though it may be difficult to determine its mode of action. In the still more remarkable and interesting cases of the spontaneous combustion of the human body, of which unfortunately there are many perfectly authenticated on record, circumstances may be pointed out which strongly indicate the influence of electricity.

The evolution of electric light from the bodies of living animals, has been noticed by several writers; and though such luminous appearances often take place without inflammation, it may be readily conceived that the electricity thus evolved, either owing to its extraordinary intensity or to the presence of highly inflammable matter, might excite combustion, and cause the destruction of a human body, as in the cases in question.

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* See Book of Science, pt. i. 2d edit. pp. 471, 472.

† "Combustion," observes Mr. Brande, "may be connected with the electrical energies of bodies; for all bodies which powerfully act upon each other are in the opposite electrical states of positive and negative; and the evolution of heat and light may depend upon the annihilation of these opposite states, which happens when they combine."—*Man. of Chem.* vol. i. p. 143.

‡ See p. 22.

Among the instances of spontaneous combustion commencing during life in the human subject, that of the Countess Cornelia Zangari and Bandi, of Cesena, has perhaps been most frequently quoted, and is therefore best known. The circumstances of this appalling accident were published in Italy, by Signor Bianchini, of Verona, and subsequently (in 1745) by Dr. Cromwell Mortimer, in the "Philosophical Transactions." This lady, who was sixty-two years of age, having been left one night by her attendant in bed asleep, was found the next morning on the floor of the room, reduced to a heap of ashes, except her arms and legs, and part of the head. The air of the apartment was loaded with fine soot, which had a noisome smell. The bed was not damaged, and the bed-clothes were lifted on one side, as usual by a person getting out of bed. Neither the floor nor furniture were injured by fire, the combustion manifestly having been excited by causes acting solely on the body, and being entirely confined to it. The countess, it seems, was accustomed, when she felt indisposed, to bathe her body with camphorated spirit of wine.

Mr. Wilmer, an eminent surgeon of Coventry, published an account of a similar occurrence, on which he had an opportunity for making observations. Mary Clues, fifty years of age, was much addicted to intoxication; and for about a year before her death, scarcely a day had passed in the course of which she had not drunk at least half a pint of rum or aniseed water. Her health gradually declined, and about the beginning of February, 1773, she was attacked by jaundice, and confined to bed. 'She still continued her habit of drinking spirits every day, and smoking a pipe of tobacco. On Saturday morning, March 1, having risen, she fell on the floor, and being too weak to get up, she remained lying there till some person came in and helped her into bed. The following night she requested to be left alone, and a woman who was with her quitted her at eleven o'clock, having shut the door and locked it according to custom. At half after five in the morning smoke was observed issuing from the window, and the room-door being speedily broken open, some flames which were in the room were soon extinguished. Between the bed and the fireplace were found the remains of the unfortunate woman. One leg and thigh were still entire; but nothing was left of the skin, muscles, or intestines. The bones of the skull, body, and arms, were wholly calcined, and covered with whitish ashes. The side of the bedstead next to the chimney was slightly burned; but the feather-bed and clothes were uninjured. The walls and every thing in the room were blackened, and the air filled with a very disagreeable vapour, though nothing except the body exhibited any strong traces of fire.

A case of spontaneous combustion is related in the "Methodist Magazine" for 1809, on the authority of Mr. Wood, a Wesleyan minister, residing at Limerick, in which the inflammation appears to have been more violent and rapidly destructive than in the foregoing instances. Mr. O'Neil, keeper of the Five Pounds Almshouses, in the city of Limerick, was awakened about two o'clock in the morning by a person knocking at his bed-room door, upon which he rose, and at the request of the person who knocked, went with him into his apartment, which was under the room occupied by a Mrs. Peacock. There they found on the floor a dead body, burning with fire, as red as copper, and which had dropped through the ceiling; for on looking up, a hole somewhat the shape of the body was perceived, the floor and rafters above having been destroyed. Mr. O'Neil immediately ran up stairs, and having burst open the door of Mrs. Peacock's room, saw the aperture in the middle of the floor, and the boards still burning. Having with assistance quenched the fire about the hole, he endeavoured to discover by what means the body had taken fire, but could find no cause. There was no candle or candlestick near the place; no fire in the grate, but what was raked up in the ashes, in the usual manner of preserving fire through the night. The room was examined; but nothing had taken fire except that part of the floor through which the body had fallen: even a small basket of twigs, and a small trunk of dry wood which lay near the hole, escaped untouched by the fire.

In most of the various cases of spontaneous combustion, more or less circumstantially related by different writers, immediate death was the consequence, or at least life had become extinct before the miserable fate of the victim was discovered. It appears, however, that death, or at all events immediate death, is not always the result of an accident of this nature. The following instance of spontaneous combustion is interesting as being one in which the party escaped destruction, and though it is but imperfectly related, yet it seems deserving of attention. It may be found in a "Treatise on the Climate, Soil, and Rivers of England," published by Dr. Charles Claromont, a physician, who was a native of Lorraine, and resided in this country in the reign of Charles II.

Two citizens of Loudun, near Poitiers, in France, having taken a walk into the country, visited a noble friend, and meeting with companions, joined them in a game with a ball.* After playing some time, they took refreshment, walked out, and then played again. They supped together pleasantly and merrily, but no one drank beyond the bounds of reason. At length, night coming on, the others returned to the town, and the two citizens remained to lodge with their friend. Retiring to their chamber, they performed their devotions, undressed themselves, and went to bed. But they had scarcely settled themselves in bed, when one of them, in terrible alarm, exclaimed that he was on fire: and truly his breast and beard taking fire, began to burn so that a part of his shirt was reduced to ashes, his bosom and chin were scorched, and the flame could scarcely be extinguished. He would doubtless have been destroyed by the conflagration, if means had not been at hand to suppress it. Dr. Claromont says he saw the man afterwards, with traces of the injury on his bosom and face; and he learned, from particular inquiry, that the combustion could not have been caused by lightning, nor by the approach of fire or candle.†

Another case of a later date, in which the sufferer survived the accident a few days, is recorded in a German journal. Don G. Maria Bertholi, a friar who lived at Mount Volere, went to the fair of Filetto, and having walked about all day, retired in the evening to the house of a relation at Fenille, to pass the night. Upon his arrival he went directly to his bed-room, and went to bed, having a handkerchief placed between his shoulders, under his shirt. In a few minutes after he had been left alone, a stifled noise, mingled with cries, was heard from his room; and when the people of the house rushed in, they found him on the floor, enveloped in a lambent flame. He was visited next day by a surgeon, who found that his body was much burned, and after suffering a good deal, he died on the fourth day after the accident.

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* Probably cricket or tennis.

† Caroli Claromontii, D. M. Nob. Lotharingi de Aëre, Locis et Aquis Terræ Angliæ. Lond. 1672, sm. 12mo, pp. 21, 22.

Such are some of the most remarkable cases of the occurrence of spontaneous combustion in living bodies, which have fallen under the notice of competent observers. Among the writers who have expressly treated of this subject, may be mentioned the names of Lecat, Kopp, Vicq D'Azyr, Dr. Thomas Trotter, Dupuytren, and M. Julia Fontenelle, the lastmentioned of whom, in a paper read before the French Academy, a few years since, draws the following conclusions from a review of the evidence on record: (1.) Spontaneous combustion generally happens to those who are accustomed to indulge immoderately in the use of vinous or spirituous liquors. (2.) Old women are the most frequent victims of such catastrophes. (3.) The combustion is sometimes very partial, but more frequently general; and the parts which most commonly escape destruction are the feet, hands, and upper portion of the head. (4.) This kind of combustion often does not extend to inflammable substances in contact with the burning body. (5.) Water, instead of quenching the fire, adds to its violence. To the circumstances thus stated as the result of the researches of M. J. Fontenelle, it may be added, that in most of the cases which have been related, the combustion appears to have commenced when the subjects of it were in bed.

As to the causes of the spontaneous combustion of the human body, though many feasible conjectures might be advanced, the phenomena by no means admit of complete explanation. It has been alleged, that the intemperate use of liquors containing alcohol may cause the production of inflammable gases within the body, and that the solids and fluids composing it may also become impregnated with undecomposed spirit. There can be no doubt that sulphuretted hydrogen gas is frequently formed in the intestinal canal, and under some circumstances other inflammable compounds of hydrogen may be accumulated in the internal cavities; spirits when swallowed in considerable quantities may possibly be interspersed in the cellular membrane; and though dram-drinkers generally become emaciated, and their bodies are thus deprived of the adipose or fatty matter proper to healthy bodies, yet oleose, and therefore inflammable particles must still be contained in some of the fluids.

Hence it may in some measure be conceived how the human body may become so much impregnated with combustible matter, as when once kindled, to be partially or almost wholly consumed, without the addition of extraneous fuel. As to the immediate or exciting cause of combustion in these cases, the direct evidence is chiefly negative. In most instances, it has been clearly ascertained, that the bodies of those who have suffered have not been set on fire by a flame or spark from any previously-ignited substance, nor by lightning. There is, however, one source to which the excitement of these alleged spontaneous combustions may with probability be attributed, because the circumstances are favourable to its production; and that is the electric spark, or the extrication of electricity possessing such a degree of intensity as is requisite to inflame combustible matter. Several instances of the evolution of electric fire from animal bodies, when excited by friction, are mentioned in the treatise on Electricity;* and others in which these appearances were accompanied with actual combustion, are noticed in Sir D. Brewster's Letters on Natural Magic.† To what circumstances the production of electric sparks, that could set fire to inflammable vapours, should be ascribed, in any given case of spontaneous combustion, can only be conjectured; but as most of the accidents referred to occurred to persons while in bed, it is not improbable that the electricity might be excited by the heat and pressure of the body on the feathers, or wool, but especially the former, constituting the stuffing of the bed.

5. This very important law of chemical affinity, is intimately connected with the second law. Though chemical combination takes place between molecules inconceivably minute, yet their union in every case is regulated by fixed and definite proportions. As to the nature of the atoms or particles of the respective bodies with which we are acquainted, we know nothing certain. For instance, each combining molecule of oxygen, of hydrogen, of carbon, or of sulphur, may consist of several component particles or sub-molecules; for there is nothing inconsistent in supposing, that though matter is not physically capable of infinite subdivision, yet that molecules may exist far more attenuated than those of the most simple substance which has hitherto

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* See Book of Science, pt. i. 2d edit. p. 469.

† See Lett. xiii. pp. 321, 322.

fallen within the range of our observation. The development of the principle involved in this law need not, however, be embarrassed by any considerations drawn from the questions that have been agitated relative to the divisibility of matter; for the term *atom* here is not to be taken in its strictest acceptation (which would imply indivisibility*), but merely as denoting the unit of combination, or the proportional mass or quantity, in which a given body unites with other bodies. It may, perhaps, be defined to be the smallest quantity to which each body or kind of matter can be reduced, without losing its essential properties as a chemical agent, and especially that property in virtue of which it enters into combination with other bodies.

The relations of the combining proportions or atomic quantities of different substances to each other, may be considered with respect either to weight or bulk. Thus 8 parts by weight of oxygen will unite with 1 part of hydrogen to form water. Supposing these to be the simplest proportions in which these bodies combine, the atomic weight of oxygen will be 8, and that of hydrogen 1. Again nitrogen will unite with oxygen in the following proportions:

14 parts by weight of nitrogen with 8 of oxygen, form nitrous oxide.
14 parts by weight of nitrogen with 16 of oxygen, form nitrous gas.
14 parts by weight of nitrogen with 24 of oxygen, form hyponitrous acid.
14 parts by weight of nitrogen with 32 of oxygen, form nitrous acid.
14 parts by weight of nitrogen with 40 of oxygen, form nitric acid.

So that the lowest proportion in which oxygen unites with nitrogen, is the same with that in which it forms water with hydrogen; and the quantity, by weight, in which nitrogen unites with oxygen in the product (nitrous oxide), is as 14 to 8, hence the former number may be taken as the atomic weight of nitrogen. Now the other numbers, denoting the combining weights of oxygen with nitrogen, are all multiples in various proportions of its atomic weight; that is, nitrous oxide contains 1 atom of oxygen, nitrous gas 2 atoms, hyponitrous acid 3 atoms, nitrous acid 4 atoms, and nitric acid 5 atoms, each atomic quantity being combined with 1 atom of nitrogen.

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* From the Greek Ἄτομος, *indivisible*, derived from the privative *α*, and τέμνω, *to cut*.

In the same manner it will be found that oxygen, in its combinations with carbon, sulphur, phosphorus, the metals, and other simple bodies, is always united to them in proportions relatively equal to its atomic weight, or to some multiple or submultiple of that weight. The following are the atomic weights, or, as they are sometimes styled, chemical equivalents of the respective bodies enumerated:

Hydrogen	1	Carbon	6
Oxygen	8	Phosphorus	12
Nitrogen	14	Sulphur	16
Sodium	24	Potassium	40
Iron	28	Copper	32
Lead	104	Mercury	200

If, then, we trace the combinations of oxygen with either of the other bodies in this table, it will appear that it unites in the ratio of 1 atom of oxygen to 1 of base, 1 to 2 of base, &c. Thus carbon combines with oxygen in two proportions, constituting two distinct compounds. In the proportion of 6 carbon to 8 oxygen, it unites to form carbonic oxide; and in that of 6 to 16 oxygen, it forms carbonic acid. Therefore 6 has been reckoned the atomic weight of carbon; and hence it will follow that carbonic oxide is a compound of 1 atom of each of its constituents, and that carbonic acid consists of 1 atom of carbon with 2 of oxygen. Further, with sulphur, oxygen may unite in three proportions: the first, or hyposulphurous acid, composed of 16 sulphur + 8 oxygen, or 1 atom of each; the second, or sulphurous acid, of 16 + 16, or 1 atom of sulphur to 2 of oxygen; and the third, or sulphuric acid, of 16 + 24, or 1 atom of sulphur to 3 of oxygen.

The various simple bodies not only combine with oxygen in quantities which are multiples or submultiples of their atomic weights, but they also combine in the same manner with other bodies. Hydrogen forms two definite compounds with sulphur. Sulphuretted hydrogen consists of 1 hydrogen + 16 sulphur, or 1 atom of each body; and supersulphuretted hydrogen of 1 + 32, or 1 atom of hydrogen, and 2 of sulphur.

If, however, we pursue the examination of the relative combining ratios of simple bodies, we shall find some, the proportions of whose compounds cannot be so satisfactorily determined, as those last mentioned. In the first place, it sometimes happens that the only known combination existing between two bodies, is not in the proportion which would be indicated by the numbers representing their respective chemical equivalents. Thus 1 hydrogen combines with 8 oxygen, and the latter with 14 nitrogen. We should therefore infer that the quantity of hydrogen which would combine with 14 of nitrogen, ought to be 1, whereas it is 3; the only known compound of the latter ingredients being ammonia, which consists of 14 by weight of nitrogen and 3 of hydrogen.

In other cases, where several combinations of two bodies occur, the ratio between the numbers is not as 1 — 2 — 3, or a multiple of the smallest, but as 1 — 1½ — 2, or some other intermediate quantity.

It may be observed, however, that in these cases, the very exception seems to prove the rule; for with regard to the first case, although 3 is not the equivalent of hydrogen, yet it is a multiple of that quantity; and with regard to the second, the relation of one-half or one-quarter of the smaller number is always preserved in the other combining quantities, so that it is plain that a certain regularity is still maintained in the midst of these apparent anomalies, and that the combinations take place even here agreeably to some fixed and settled principle.

Many of these exceptions, indeed, have disappeared in proportion to the progress of discovery: thus a few years ago we were acquainted with only two compounds of sulphur and oxygen, the sulphurous and sulphuric acids, the former composed of 16 sulphur and 16 oxygen, the latter of 16 sulphur and 24 oxygen, the proportion of oxygen in the two compounds being therefore as 2 to 3. But the discovery of the hyposulphurous acid has since removed this anomaly, by presenting us with a compound of 16 sulphur and 8 oxygen, so that the proportion of the latter is to that in which it exists in the second, as 1 to 2. It is probable, then, that in many cases the exception is only apparent, whilst in others it seems not unlikely that two equivalents of one ingredient may combine respectively with two, three, and four equivalents of the other, as in the oxides of lead, which, according to Dr. Thomson, consist of

Lead $104 \times 2 = 208$ . . . Oxygen $8 \times 2 = 16$
—— $104 \times 2 = 208$ . . . —— $8 \times 3 = 24$
—— $104 \times 2 = 208$ . . . —— $8 \times 4 = 32$*

It will be perceived on reference to the preceding estimates of atomic weights, that they are all multiples or submultiples of the atomic weight of hydrogen, that being unity. Hydrogen being the lightest of all the bodies with which we are acquainted, there is a degree of convenience in making its combining weight the standard from which those of others are to be calculated. It must, however, be understood, that the combining weights or chemical equivalents have no reference to any real standard existing in nature, but that they merely denote the relative quantities in which different substances combine together, and it is immaterial what numbers are adopted to express those quantities, provided the entire series exhibits the same proportions throughout. Thus 10 might be fixed on as the atomic weight of hydrogen, in which case that of carbon would be 60, that of oxygen 80, that of sulphur 160, that of iron 280, and so on, all being augmented in tenfold proportion. The combining number of hydrogen might be reckoned 100 or 1000, and those of the others increased in the same ratio; or any given number whatever might be selected instead of unity, and a scale of combining quantities formed to correspond with it. But the obvious advantages of taking a series commencing with unity must at once be perceived. All chemists, however, are not agreed as to the propriety of making the atom of hydrogen the foundation of the scale of equivalents. Thus Dr. Thomson reckons the atomic weight of oxygen as 1, and consequently that of hydrogen $\frac{1}{8}$ or 0.125, that of carbon $\frac{1}{6}$ or 0.75, and that of sulphur $\frac{16}{8}$ or 2; and alters the series throughout in the same ratio. Others have fixed on 10 or 100 as the combining number of oxygen, and regulated their scales accordingly.

The preceding observations will enable the reader to understand in some degree the causes of the varieties of the atomic weights attributed by different writers to the same body; some estimating the weight with reference to that of hydrogen as the standard, and some with reference to oxygen. There is, however, another source of discrepancy, which must not be left unnoticed. The determination of the atomic weights of bodies must in the first instance depend on chemical analysis: and, as Professor Daubeny observes, "we must admit that it is doubtful whether such accuracy in chemical analysis has yet been attained, as to enable us to answer positively for a fraction not exceeding the 300th or 400th part of the whole quantity to be determined; and this degree of exactness at least would have been required to verify the law satisfactorily in the higher parts of the scale."* Hence it is that Berzelius, estimating the atomic weights of different bodies with reference to hydrogen, has given numbers varying more or less from those which have been generally adopted; his numbers being founded on his own analyses. The well-known skill and talent for research of this celebrated chemist, afford strong presumptions in favour of the accuracy of his conclusions, which have been generally confirmed by more recent experiments of Dr. Turner, Professor of Chemistry in the University of London. This gentleman states, as the result of his investigations, that "without denying the possibility of hereafter tracing some simple relation between the equivalents of bodies, he is convinced that the hypothesis of *all equivalents being multiples by a whole number of the equivalent of hydrogen*, is inconsistent with the best analyses which chemists at present possess."†

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* Introduction to the Atomic Theory, by Charles Daubeny, M.D., F.R.S., Prof. of Chem. at Oxford. 1831, 8vo, pp. 42, 43.

The best tables or scales of chemical equivalents, therefore, which have been hitherto produced, are to be considered as by no means perfect, nor in the present state of our knowledge capable of being rendered so; but notwithstanding their admitted defects, they may be provisionally adopted, as affording facilities for making calculations of the contents of compound bodies, or for checking the results of experiment, by reference to the combining proportions of bodies which have been submitted to analysis.

A most ingenious and useful modification of the system of atomic weights was contrived by Dr. Wollaston, constituting his *Logometric Scale of Chemical Equivalents*. It is similar in principle to the common sliding rule, and like that instrument, has the usual Gunter's line, or scale of logometric numbers, on the slider; and upon a line adjacent to the slider, are marked certain points, corresponding to the numbers that represent the combining weights of the various elementary bodies, and of the acids, alkalies, and other chemical compounds. Thus it is so constructed that when the number 10, which is reckoned the atomic weight of oxygen, stands opposite to the name of that body, hydrogen will stand opposite 1.25, carbon opposite 7.5, nitrogen opposite 17.5, iron opposite 35.0, and sulphur opposite to 20. Hence, if we wish to know how much of either of these bodies, as for instance, iron, will form a binary combination with a given quantity of oxygen, as 14.5, we bring that number on the slider opposite the word oxygen in the scale, and the number 50 will stand opposite the word iron; indicating that 50 parts by weight of iron will combine with 14½ of oxygen to form protoxide of iron. And in the same manner it will be seen how much of any other body will combine with any given quantity of oxygen.*

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* Introd. to the Atomic Theory, p. 39.

† Second Report of the British Association, 1832, p. 572.

As the combining atoms of bodies bear certain relations to each other by weight, so likewise, in some states they manifest corresponding relations as to bulk or volume. Not long after Mr. Dalton in England had directed the attention of chemists to the relation existing between the weights of bodies which combine in different proportions, MM. Gay Lussac and Humboldt in France established a similar correspondence between the volumes of oxygen and hydrogen, which unite together, proving that they combined in the proportion of one volume of the first to two of the second. Shortly after the French philosophers extended the same inference *generally* to the combinations between gases; showing that they united in the exact proportions of 1 volume of the one, to 1, 2, 3, or some other whole number of volumes of the second. Thus one volume of carbonic acid, and one volume of ammonia, form carbonate of ammonia; one of nitrogen and three of hydrogen form ammonia; one of chlorine and one of hydrogen form muriatic acid. The same law applies to vapours, such as those of alcohol and ether, as well as to true gases. M. Gay Lussac even rendered it probable that the combinations between solids and gases follow the same principle: that quantity of the former uniting with one or more volumes of the latter, which, if existing in the form of vapour, would have occupied a correspondent bulk. Thus carbon 6 and oxygen 16, by weight, form carbonic acid; hence 100 cubic inches of oxygen will combine with 12.7 grains of carbon. For 100 cubic inches of oxygen weigh 33.8888 grains, and, as 16 : 6 :: 33.8888 : 12.7. Now 12.7 grains of carbon may be shown to occupy when in vapour 100 cubic inches, or exactly the same space as 33.8888 grains of oxygen, so that the combining quantities of the two bodies correspond in volume no less than in the number of atoms of which a volume of each is made up.

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* See Paper on a Synoptic Scale of Chemical Equivalents, by Dr. Wollaston; in Philos. Trans. for 1814.

"When aëriform fluids combine together, and produce by their union a new gas, they generally contract in bulk, or occupy less space than they did when separate. Now M. Gay Lussac found that when this takes place, they contract either to one-half, one-quarter, one-third, two-thirds, or some other quantity bearing an exact proportion to their antecedent bulk. Thus carbonic oxide 2 volumes, with oxygen 1 volume, form together 2 volumes of carbonic acid gas, there being a contraction of one-third; 3 volumes of hydrogen and 1 of nitrogen, form 2 volumes of ammonia, the gases contracting to one-half, and so with the rest."*

These facts exhibit the doctrine of combining quantities in a new point of view, and serve to corroborate the inferences concerning the atomic constitution of bodies drawn from the consideration of the relations that have been shown to subsist between the weights of chemical equivalents. When we attempt, however, to reconcile the principle of combining weights with that of combining volumes, difficulties occur which can only be completely dissipated by future researches. Thus we find that 100 cubic inches of oxygen gas will combine with 200 cubic inches of hydrogen, to form 200 cubic inches of aqueous vapour; so that the quantity of the hydrogen in water by measure, is double that of the oxygen. Hence Sir H. Davy concluded that an atom of water consisted of 2 atoms of hydrogen and 1 of oxygen; and therefore that the atom of the latter should be represented by 16, that of the former being unity. This estimate of the weight of an atom of hydrogen as being $\frac{1}{16}$ that of an atom of oxygen is inconsistent with the combining proportions of hydrogen in other cases, and it has consequently been rejected, while that originally proposed by Dr. Dalton, which rates the two volumes of hydrogen as one atom, has been preferred in making computations. Dr. Prout, however, is disposed to adhere rigorously to the principle of equivalent volumes rather than that of combining weights. He says, "It has been found by experiment, that the same volumes of different bodies in the gaseous states have very different weights. Thus, for instance, a volume of oxygen weighs sixteen times as much as the same volume of hydrogen. Hence, as the number of self-repulsive molecules in each of these gases is presumed to be the same,* the weight of the self-repulsive molecule of oxygen must, of course, be sixteen times greater than that of hydrogen; and generally, the weights of the self-repulsive molecules of all bodies, will be as the specific gravities of these bodies in the gaseous state, or will bear certain simple relations to these specific gravities."† He subsequently remarks, that "a strictly philosophical arrangement, supposing the principles we have advanced to be well founded, would require that *the volume in all instances should be made the molecular unit*; in which case the relative weights of the self-repulsive molecules of hydrogen and oxygen, as above mentioned, will be as 1 to 16."‡

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* Daubeny's Introd. to the Atomic Theory, pp. 45, 46.

From the doctrine of relations between combining atoms or self-repulsive molecules and combining volumes adopted by Dr. Prout, it will directly follow, as he observes, that the atoms of bodies will be as their specific gravities, or have certain relations to their specific gravities. Hence the determination of the exact specific gravities of the gases is of the utmost importance. Unfortunately in the results hitherto obtained from their experiments and calculations, chemists agree as little in their estimates of specific gravities, as in those of atomic weights. Till these can be ultimately determined through the continued researches of philosophical inquirers, we must employ the most accurate approximations which can be deduced from the information already obtained. In this point of view the following table of the specific gravities of aërial bodies, from Brande's Journal of Science, vol. iii., is deserving of attention. It was drawn up by Professor Meinecke, of Halle, in Saxony, from stoechiometric calculations, founded on the comparison of the experiments of various chemists on the different elastic fluids.

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* The presumption that equal volumes of different gases contain exactly the same number of atoms, is founded chiefly on a law propounded by Mariotte, that the volume of any gas is inversely as the pressure applied to it; since it is supposed that if the number of atoms in each gas was not the same, the law of diminution of volume under pressure would vary with respect to the different gases. It appears, however, from the most exact experiments, that this law strictly applies only to the permanent gases, as oxygen, hydrogen, and nitrogen, which cannot be reduced to the liquid state by extreme pressure and low temperature; and these gases at any given temperature diminish in volume under pressure in the same ratio with atmospheric air. But sulphurous acid and other condensable gases, submit to pressure more readily than common air. V. Mitscherlich's Introduction to Chemistry, vol. i. p. 131; and Johnston's Report on Chem. Science to the British Association, 1832, pp. 420, 421, 451. Hence it must be admitted, that Mariotte's law, while it fails with respect to condensable gases or vapours, at least holds good with regard to oxygen and hydrogen.

† Dr. Prout's Chemistry, Meteorology, &c., p. 134.

‡ Id. p. 135.

Table of the Specific Gravities of Gases and Vapours.

	Sp. Gr. rel. to Atm. Air.	*Sp. Gr. rel. to Hyd. G.*	*Sp. Gr. rel. to Oxygen Gas.*
1. Hydrogen gas	0.0694	1	0.0625
2. Protocarburetted hydrogen gas	0.5555	8	0.5
3. Azotated hydrogen gas, or ammonia	0.5901	8½	0.5312
4. Vapour of the protoxide of hydrogen, or aqueous vapour	0.6250	9	0.5625
5. Vapour of hydrocyanic acid, or prussic acid	0.9374	13½	0.8437
6. Gaseous protoxide of carbon, or carbonic oxide	0.9722	14	0.875
7. Percarburetted hydrogen gas, or olefiant gas	0.9722	14	0.875
8. Azote, or nitrogen gas	0.9722	14	0.875
9. Atmospheric air	1.	14⅖	0.9
10. Gaseous deutoxide of azote, or nitrous gas	1.041	15	0.937
11. Oxygen gas	1.111	16	1.
12. Hydrosulphuric gas, or sulphuretted hydrogen	1.159	17	1.062
13. Hydrochloric gas, or muriatic acid gas	1.274	18½	1.156
14. Carbonic acid gas	1.527	22	1.375
15. Gaseous protoxide of azote, or nitrous oxide	1.527	22	1.375
16. Alcoholic vapour	1.597	23	1.437
17. Vapour of cyanogen	1.806	26	1.625
18. Chlorocyanic acid vapour	2.153	31	1.937
19. Sulphurous acid gas	2.222	32	2.
20. Chlorine	2.5	33	2.25
21. Ethereal vapour	2.569	37	2.312
22. Nitrous acid vapour	2.638	38	2.375
23. Percarburet of sulphur, or sulphuret of carbon	2.638	38	2.375
24. Carbochloric acid, or phosgene gas	3.473	50	3.125

6. The object of this law of chemical affinity is to determine the influence of circumstances on the combination of bodies with each other. (1.) With respect to those cases where compounds are formed from the mere mixture of their constituent parts, but few observations will be requisite. Some bodies exert no action on each other, when placed in contact under any given conditions; and therefore, so far as our knowledge extends, are to be considered as incapable of union. The simple bodies in general have a strong tendency to combine together; but when two compound bodies are intermixed, it will frequently happen that instead of forming a mingled mass or a single chemical compound, they will decompose each other. Among the circumstances that facilitate the union of bodies are intermixture and augmentation of temperature, the effects of which have been noticed in treating of the second and third laws of affinity.

(2.) In the case of single elective attraction, exhibited in the decomposition of a compound body when a simple body is presented to it, the phenomena will depend on the relative affinity of the latter for one of the elements of the former. The series of decompositions adduced to exemplify the first law of chemical affinity may be referred to as exhibiting to a certain extent the relative affinities of the several bodies. The law of elective attraction on which such decompositions depend is, however, subject to some important modifications. It has been stated, that lime separates ammonia from its combination with sulphuric acid. (See p. 23.) "Bergmann conceived that such decompositions were *solely* determined by chemical attraction, and that, consequently, the order of decomposition represented the comparative forces of affinity: and this view, from the simple and natural explanation it afforded of the phenomenon, was for a time very generally adopted. But Bergmann was in error. It does not necessarily follow, because lime can separate ammonia from sulphuric acid, that the lime has a greater attraction for the acid than the volatile alkali. Other causes are in operation which modify the action of affinity to such a degree, that it is impossible to discover how much of the effect is owing to that power. It is conceivable that the ammonia may in reality have a stronger attraction for sulphuric acid than lime, and yet the lime, from the great influence of disturbing causes, might succeed in decomposing sulphate of ammonia. The justice of the foregoing remark will be made obvious by the following example: When a stream of hydrogen gas is passed over the oxide of iron heated to redness, it deprives the iron of its oxygen entirely, combining with it so as to form water. On the contrary, when watery vapour is brought into contact with red-hot metallic iron, the oxygen of the water quits the hydrogen, and combines with the iron. It follows, from the result of the first experiment, according to Bergmann, that hydrogen has a stronger attraction for oxygen than iron has; and from the second, that iron has a greater affinity for oxygen than hydrogen has. But these inferences are incompatible with each other. The affinity of hydrogen for oxygen must be either equal to that of iron, or greater, or less. If the first is the case, then the result of both experiments was determined by modifying circumstances; since neither of these substances ought, on this supposition, to take oxygen from the other. If the second, then the decomposition, in one of the experiments, must have been determined by extraneous causes, in direct opposition to the tendency of affinity."*

The fallacy of Bergmann's inferences relative to the absolute effect of affinity in the production of chemical decompositions was first pointed out by Berthollet, who demonstrated that tables of decomposition cannot be considered as indicating, under all circumstances, the order of affinity of bodies. He also showed, that the action of affinity is modified by various causes, of the operation of which in a variety of cases he gave a consistent explanation. That philosopher, however, overrated the influence of occasional causes on the phenomena of decomposition, when he attributed them to such causes only, denying the existence of elective affinity as an invariable force. Dr. Turner observes, "That chemical attraction is exerted between bodies with different degrees of energy is indisputable. Water has a much greater affinity for muriatic acid and ammoniacal gases than for carbonic acid and sulphuretted hydrogen, and for these than for oxygen and hydrogen. The attraction of lead for oxygen is greater than that of silver for the same substance. The disposition of gold and silver to combine with mercury is greater than the attraction of platinum and iron for that fluid. As these differences cannot be accounted for by the operation of any modifying causes, we must admit a difference in the force of affinity in producing combination. It is equally clear, that in some instances the separation of bodies from one another can only be explained on the same principle. No one, I conceive, will contend that the decomposition of hydriodic acid by chlorine, or of sulphuretted hydrogen by iodine, is determined by the concurrence of any modifying circumstances."[*]

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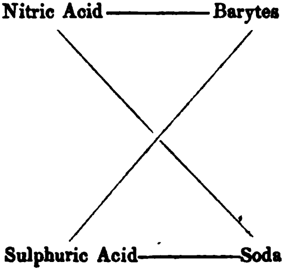
* Dr. Turner's Elements of Chemistry, 4th ed. 1833, pp. 167, 168.

(3.) Complex elective attraction differs from that already described, in exhibiting a more complicated play of affinities; and hence it is in such cases that anomalous appearances occur, from the influence of disturbing causes. Compounds may be decomposed by means of complex affinity, when they resist the operation of simple affinity. Thus nitric acid alone will not decompose sulphate of soda, for the sulphuric acid combined with the soda has a stronger affinity for that alkali than the nitric acid; but if a solution of nitrate of barytes, or the compound of nitric acid with the earth called barytes, be added to a solution of sulphate of soda, a double decomposition will take place, the sulphuric acid quitting the soda to unite with the barytes, and the nitric acid separating from the earth to combine with the alkali; and the result will be two new compounds, namely, sulphate of barytes and nitrate of soda. Such processes of complex affinity may be conveniently exhibited by means of a diagram, which appears to have been first employed by Dr. Black. The result of the decompositions just described might be thus represented:



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[*] Elements of Chemistry, p. 168.

In any given case, the relative affinities of the substances for each other may be denoted by numbers. When two salts are brought within the sphere of mutual action, they will not become decomposed, unless the affinities which tend to form new compounds are superior to those which tend to keep the constituents of the original compounds united. Mr. Kirwan adopted the term *divellent* affinity, to signify that attraction which favours decomposition; and quiescent affinity, for that which opposes a change of state.

The effect of peculiar circumstances on complex affinity may be observed when carbonate of lime is mixed with muriate of ammonia, and the two salts in a dry state are exposed to heat; double decomposition takes place, and carbonate of ammonia and muriate of lime are produced: and, on the contrary, if a solution of carbonate of ammonia in water be mixed with a solution of muriate of lime, decomposition will also take place, the lime will unite with the carbonic acid, and the ammonia will enter into combination with muriatic acid. The decomposition which occurs in this case, however, is more extensive than might at first be suspected. What is called muriate of lime is really a chloride of calcium, or the metal which forms the basis of lime. Now, when carbonate of lime and muriate of ammonia are heated together, both the lime and the muriatic acid are decomposed, the oxygen of the lime and the hydrogen of the acid being driven off; while the metallic calcium enters into union with the chlorine from the muriatic acid, and the carbonic acid which was united with the lime combines with the ammonia. The decomposition of the carbonate of ammonia and chloride of calcium, by mixing their solutions, may be similarly explained; for the chloride of calcium decomposes water, the oxygen of which combines with the metal to form lime, and the hydrogen unites with the chlorine thus set free to form muriatic acid, which separates the carbonic acid from the ammonia to combine with it, leaving the latter acid to form a union with the lime.

Another case of reciprocal decomposition may here be mentioned, which does not so readily admit of explanation. Sir H. Davy has remarked, that "in many cases, decompositions that cannot be produced by single attractions, may be produced by double affinities. Thus the elements of sulphate of barytes, or the combination of sulphuric acid with the earth called barytes, are so firmly united, that no alkali, nor earth, will separate the acid from the barytes. Potash, which has a very strong attraction for the acid, will not decompose it alone; but if potash combined with carbonic acid be digested for some time with powdered sulphate of barytes, there is a double decomposition; and combinations of sulphuric acid and potash, and carbonic acid and barytes, are formed."* It appears, however, from experiment, that not only may the decomposition stated take place to a certain extent, but that likewise, *under similar circumstances*, sulphate of potash will decompose carbonate of barytes. Mr. Richard Phillips found, that on boiling 100 parts of sulphate of barytes and 59 parts of carbonate of potash, for two hours, in four ounces of water, more being added, from time to time, to supply the loss from evaporation, 23 parts only of the sulphate of barytes were decomposed, producing 19.5 of carbonate of barytes. As the converse of this experiment, he then, in the same manner, boiled 85 parts of carbonate of barytes with 74 of sulphate of potash, and found that 57 parts of the carbonate were decomposed, yielding 67 parts of sulphate of barytes. From these and other experiments, Mr. Phillips infers that the complete decomposition of the salts, in either case, is prevented by the reproduction, during the process, of the insoluble compounds.† M. Dulong had been previously engaged in researches on the same subject, from which were drawn the following conclusions: 1. That all the insoluble salts are decomposed by the carbonates of potash or soda; but that a *complete* exchange of principles of these salts cannot take place. 2. That all the soluble salts, of which the acid forms with the base of the insoluble carbonate an insoluble salt, are decomposed by these carbonates, until the decomposition has reached a certain limit, which it cannot pass.‡

7. It has been remarked, in the discussion of the preceding law of chemical affinity, that when compound bodies are brought within the sphere of each other's action, they may be mutually decomposed, or they may combine to form sur-compounds. This last result is what takes place when acids unite with metallic oxides to constitute salts,

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[*] Elements of Chemical Philosophy, p. 103.

[†] See paper "On an Anomalous Case of Chemical Affinity," by R. Phillips, in Jour. of Science, ed. at R. I., vol. i.

[‡] See Annales de Chimie, vol. lxxii.; and Dr. Ure's Dict. of Chemistry, art. ATTRACTION.

or when oils and alkalies are united to form soaps. Hence a distinction of bodies has been made into *primary compounds* and *secondary compounds*; and these again have been variously subdivided by systematic writers. The primary compounds are not all formed by the simple union of two bodies: those which are thus constituted may be termed binary compounds, which, next to the simple bodies themselves, are of the utmost importance. Next to these may be placed the primary compounds with double bases; such as the tartaric, citric, malic, and other acids, in which hydrogen and carbon unite to form the respective bases, which combine with oxygen; the prussic or hydrocyanic acid, consisting of cyanogen, a compound of carbon and nitrogen, acidified by hydrogen; and an acid which has been termed the hydrozanthic, the base of which is carbon and sulphur, as in the last case, acidified by hydrogen.

The primary compounds may be systematically arranged in three principal classes: 1. Acids; 2. Bases; and 3. Neutrals.

The term Acid was formerly used to denote certain substances characterized by their sour taste, the property of changing the blue colour of vegetables to red, and that of combining with alkalies and certain earths to form salts, or as they were termed neutral salts: all the bodies regarded as acids being liquids, or else gases or solids, capable of being readily reduced to the liquid form, by uniting with water. Lavoisier having found that some of the most powerful of the acids, as the sulphuric and the nitric, were composed of certain bodies united to a large proportion of oxygen, concluded that oxygen was the general acidifying principle, and therefore considered all acids as compounds containing an excess of oxygen. This doctrine was rendered untenable by the discovery of properties regarded as characteristic of acids (such as the reddening of vegetable blues, and the formation of salts with alkalies), in the compound of sulphur with hydrogen, or sulphuretted hydrogen; and by the discovery of Davy relative to the nature of chlorine, and the constitution of muriatic or hydrochloric acid. Subsequent researches have furnished reasons for extending the appellation of acid to certain compounds of chlorine, iodine, bromine, fluorine, hydrogen, sulphur, selenium, and some of the metals; and the acids containing oxygen have been styled oxacids, by way of distinction. On the same principle have been formed the terms chloracids, iodacids, bromacids, fluoracids, hydracids, sulphuracids, &c. But the state of science at present hardly enables us to discriminate properly between such of the various combinations of the simple substances above mentioned as correspond with the acid compounds of oxygen, and those corresponding with the oxides.

The primary compounds called Bases include such as have been heretofore termed alkalies, earths, and metallic oxides. The alkalies, except ammonia, are now known to be oxides; three of the four alkalies with simple bases, lithia, potash, and soda, being oxides of certain metals, and the other, ammonia, a combination of hydrogen with nitrogen, which might therefore be styled nitroguret of hydrogen. Besides these, there are a number of newly-discovered alkalies, having compound bases, and chiefly procurable from vegetable substances, as morphine, from opium; strychnin, from nux vomica: and cinchonin and quinine, from Peruvian bark. Such of these alkalies as have been analyzed are found to be oxides with bases composed of various proportions of hydrogen and carbon, and in some cases of hydrogen, carbon, and nitrogen. The earths, like most of the alkalies with simple bases, are metallic oxides. Silica, however, long classed among the earths, though a compound of oxygen with a simple base, differs from the rest in various respects, acting the part of an acid in the formation of the numerous mineral compounds in which it is contained.

Among the primary compounds, those termed chlorides, iodides, bromides, &c., with most of which we are yet but very imperfectly acquainted, will nevertheless probably prove to be an interesting and important class of bodies; and this will hardly be questioned when it is considered that chloride of sodium, or common salt, and chloride of calcium, improperly called muriate of lime, are among the bodies in question.

Of the primary compounds termed Neutrals it will be sufficient here to state, that Dr. Thomson has arranged them under seven heads, namely, water, alcohol, volatile oil, fixed oil, bitumen, and ethal, an oleose kind of matter which Chevreul, a French chemist, procured from spermaceti.

The most important of the secondary or sur-compounds, are those arising from the combination of acids with bases. Those best known are the compounds of the oxacids with the alkalies with simple bases, or with certain of the earths and metallic oxides. As examples may be mentioned, sulphate of soda (Glauber salt), nitrate of potash (saltpetre), sulphate of magnesia (Epsom salt), and acetate of lead (sugar of lead). All these, as well as many others that might be named, are readily soluble in water; thus corresponding with the popular notion of salts. But other compounds of acids and metallic oxides are insoluble, as carbonate of lime (chalk), sulphate of barytes (ponderous spar), sulphate of lead, and phosphate of mercury. Some salts have compound bases, as alum, which is a sulphate of potash and alumine; nitrate of ammonia and magnesia, phosphate of ammonia and soda, sulphate of ammonia and oxide of iron, muriate of ammonia and magnesia, &c. The acids with compound bases also unite with the alkaline and other bases to form salts. Of this description are the sulpho-cyanate of lime, the salts formed by the prussic acid, and the numerous salts formed by the acetic, tartaric, and other hydro-carbonous acids.

It was from the analysis of the neutral salts, and the observation of the relation of the combining quantities of the various salts to each other, that Wenzel and Richter were led to those speculations on chemical affinities, which furnished a foundation for the more extensive researches of Dalton, Berzelius, and other philosophers, relative to the theory of definite proportions. As binary compounds consist of certain numbers of atoms or equivalents of their constituent parts, so when they enter into new combinations, forming sur-compounds, they unite in proportions which bear certain relations to the combining numbers of those constituents. Thus the combining numbers or equivalents of compound bodies, as salts, are the sums of those of the acids and bases of which they are formed. As, for instance, potash consists of potassium, atomic weight 40, and oxygen, atomic weight 8, and as it contains an atom of each, its combining number, or atomic weight is 48; so sulphuric acid is composed of sulphur, atomic weight 16, and oxygen 8, and consisting of one atom of sulphur to three of oxygen, its atomic weight must be $3 \times 8 = 24 + 16 = 40$; hence sulphate of potash will have for its combining weight $48 + 40 = 88$. The atomic weights or combining proportions of other salts are in the same manner derived from those of their constituents; and when they enter into new chemical combinations, such always take place with reference to their atomic weights, or multiples of those weights.

Berzelius concludes, from numerous experiments on a vast variety of bodies, that the law of combination by definite proportions, pervades the whole of nature, and that it extends not only throughout the productions of the mineral kingdom, but also to those derived from animals and vegetables.

SIMPLE BODIES AND THEIR PRIMARY COMPOUNDS.

Among those that are considered as elementary bodies, there are many that seem to be of little importance in the economy of nature, since they are never found in an uncombined state; and from the most recent researches of chemists, it may be concluded that they exist but in minute quantities in their several compounds. It is from the union of a few elementary or simple substances, that the vast variety of the forms of matter observable in the animal, vegetable, and mineral kingdoms are chiefly produced. Organized bodies, though their proximate elements are often the result of complicated combinations, yet the ultimate products of their analysis are generally few in number. Vegetables, when their complete decomposition is effected, are found to consist principally of oxygen, hydrogen, and carbon; and animal matter, when submitted to the crucible of the chemist, hardly yields a greater variety of products, being chiefly distinguishable from vegetable substances, as affording nitrogen or azote, in addition to the simple bodies just mentioned. It is true that sulphur, phosphorus, and some of the metals, as iron and manganese, sometimes enter into the composition of both animals and vegetables, but in relatively small quantities. In the mineral kingdom, a more copious variety of ultimate products occurs, including, of course, those simple bodies which are not found in animals or vegetables. But even here the ultimate elements of the great masses which constitute the mineral crust of the terrestrial globe are so distributed, that a relatively small number of them only enter into the composition of the most abundant and widely distributed compounds. Some interesting speculations on the relative quantities of the simple substances contained in the earth's crust, have been advanced by Mr. De la Beche.

"The principal substances entering into the chemical composition of our planet's surface may be classed in the following order, according to the respective importance of each:

Simple Non-metallic Substances.

1. Oxygen
2. Hydrogen
3. Nitrogen
4. Carbon
5. Sulphur
6. Chlorine
7. Fluorine
8. Phosphorus.

Metallic Bases of the Alkalies and Earths.

1. Silicium*
2. Aluminum
3. Potassium
4. Sodium
5. Magnesium
6. Calcium.

Metals, the Oxides of which are neither Earths nor Alkalies.

1. Iron
2. Manganese.

"It would appear, therefore, that sixteen substances, commonly considered simple, constitute, by their various combinations, if not entirely, at least by far the largest amount of all the matter which, either gaseous, liquid, or solid, organic or inorganic, is known to exist on the surface of the earth."†

Since, then, these bodies, through their relative affinities, exercise so extensive an influence over that portion of the universe with which we are acquainted, they obviously claim the fullest investigation, with respect to their individual properties and several combinations. Some of those bodies, however, which are comparatively rare, are still, on various accounts, curious and interesting; and all the simple substances require some further notice. The remainder of this treatise, therefore, will contain a brief account of the chemical properties of the simple bodies of both classes, and of those of their most important compounds.

Table of Binary Compounds of the Non-metallic Elements.

Chlorine.

Protoxide, 1 Ch. 1 Ox.
Peroxide, 1 Ch. 4 Ox.
Chloric Acid, 1 Ch. 5 Ox.
Oxychloric Acid, 1 Ch. 7 Ox.
Muriatic Acid.

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* Mr. De la Beche ranks the base of siliceous earth among the metals; but Berzelius and other recent writers reckon it among the non-metallic elements. See p. 17.

† Researches on Theoretical Geology, 1834, pp. 23, 24.

Iodine.

Iodic Acid, 1 I. 5 Ox.
Chloriodic Acid, 2 I. 1 Ch.

Bromine.

Bromic Acid, 1 Br. 5 Ox.
Chloride of Bromine.

Fluorine.—*Hydrofluoric Acid.*

Hydrogen.

Water, 1 H. 1 O.
Peroxide of Hydrogen, 1 H. 2 Ox.
Muriatic Acid, 1 H. 1 Ch.
Hydriodic Acid, 1 H. 1 I.
Hydrobromic Acid, 1 H. 1 B.
Hydrofluoric Acid, 1 H. 1 F.

Nitrogen.

Atmospheric Air.
Nitrous Oxide, 1 N. 1 Ox.
Nitric Oxide, 1 N. 2 Ox.
Hyponitrous Acid, 1 N. 3 Ox.
Nitrous Acid, 1 N. 4 Ox.
Nitric Acid, 1 N. 5 Ox.
Chloride of Nitrogen, 1 N. 3 Ch.
Iodide of Nitrogen, 1 N. 3 I.
Ammonia, or Nitroguret of Hydrogen, 1 N. 3 H.

Carbon.

Carbonic Oxide, 1 C. 1 Ox.
Carbonic Acid, 1 C. 2 Ox.
Oxalic Acid, 2 C. 3 Ox.
Protochloride of Carbon, 1 C. 1 Ch.
Perchloride of Carbon, 2 C. 3 Ch.
Iodide of Carbon, 1 C. 1 I.
Sesqui-iodide of Carbon, 2 C. 3 I.

Carbon *continued.*

Bromide of Carbon.
Subcarburet of Hydrogen, 1 C. 2 H.
Carburet of Hydrogen, 2 C. 2 H.
Bicarburet of Hydrogen, 2 C. 1 H.
Quadricarburet of Hydrogen, 4 C. 4 H.
Naphtha.
Caoutchouc.
Cyanogen, 2 C. 1 N.

Boron.

Boracic Acid, 1 B. 2 Ox.
Chloride of Boron, 1 B. 2 Ch.
Fluoride of Boron, 1 B. 3 F.

Silicon.

Silex or Silicic Acid, 1 Si. 3 Ox.
Chloride of Silicon.
Fluoride of Silicon, 1 Si. 1 F.

Phosphorus.

Phosphorous Acid, 2 Ph. 3 Ox.
Phosphoric Acid, 2 Ph. 5 Ox.
Hypophosphorous Acid, 2 Ph. 1 Ox.
Chloride of Phosphorus, 1 Ph. 1 Ch.
Perchloride of Phosphorus, 1 Ph. 2 Ch.
Iodide of Phosphorus.
Periodide of Phosphorus, 1 Ph. 2 I.
Bromides of Phosphorus, $\begin{cases}\text{1 Ph. 3 Br.}\\ \text{1 Ph. 5 Br.}\end{cases}$
Phosphuretted Hydrogen, 1 Ph. 1 H.
Subphosphuretted Hydrogen, 1 Ph. 3 H.
Phosphuret of Carbon, 1 Ph. 1 C.

Sulphur.

Hyposulphurous Acid, 1 S. 1 Ox.
Sulphurous Acid, 1 S. 2 Ox.

Sulphur *continued.*

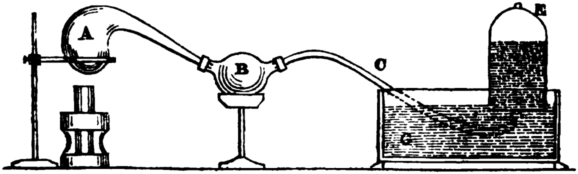
Hyposulphuric Acid, 2 S. 5. Ox.
Sulphuric Acid, 1 S. 3 Ox.
Chloride of Sulphur, 1 S. 1 Ch.
Iodide of Sulphur.
Bromide of Sulphur.
Sulphuretted Hydrogen, 1 S. 1 H.
Super-sulphuretted Hydrogen.
Sulphuret of Carbon, 2 S. 1 C.
Sulphuret of Phosphorus, 1 S. 1 Ph.

Selenium.

Selenious Acid, 1 Se. 2 Ox.
Selenic Acid, 1 Se. 3 Ox.
Protochloride of Selenium, 2 Se. 1 Ch.
Perchloride of Selenium, 1 Se. 2 Ch.
Hydroselenic Acid, 1 Se. 1 H.

Oxygen.

The gaseous body, named by the French chemists Oxygen, or the acidifying principle,* may be obtained in a simple or uncombined state by several different processes, and especially by the application of heat to the combinations of oxygen with certain metals, as mercury, manganese, or lead.



The apparatus exhibited above affords a convenient method for the production of this gas by the decomposition of metallic oxides. Let a small quantity of red oxide of lead (Minium, or red lead), be introduced into the retort A, the beak or opening of which is connected with the double-necked glass globe B, from which proceeds the bent tube C, terminating under the tall glass jar E, the lower end of which is immersed in the water-trough G. If then the retort be heated by a lamp, after the atmospheric air contained in the vessels and tube has been suffered to escape, the cylindrical jar filled with water and inverted, is to be placed over the lower end of the tube, as represented in the figure; and the oxygen gas, as it is formed by the decomposition of the oxide, will pass over, and rising in bubbles through the water in the jar, will collect in the upper part of it. This gas may be procured in the same manner, by substituting for the oxide of lead, red oxide of mercury, or black oxide of manganese. This last being a cheap substance, is generally used for obtaining oxygen gas on a large scale; and for that purpose the distillation is conducted in an iron retort, luted to a gun-barrel, and the former exposed to the heat of a furnace. When obtained by this last mode, however, the gas is not very pure, and the quantity produced from a given weight of the oxide is extremely variable.

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* From the Gr. Ὀξὺς, *acid*, and Γεννάω, *to generate*, or *produce*. The German chemists style this body SAUERSTOFF, literally *sour stuff*.

As there is a great number of substances in which oxygen is contained, so it may be procured by various other processes. When wanted for experiments of research, and therefore in a state of the greatest purity, about 100 grains of the salt called chlorate of potassa (formerly oxymuriate of potash), may be introduced into a retort with a bent tube fitted to it, the open end of which must pass under the mouth of a jar filled and inverted in a water-trough. The retort is then to be heated by the flame of a large spirit-lamp, and after the atmospheric air contained in it has been driven off, and the salt fuses and appears to boil, oxygen gas will be formed, and may be collected as before, in the jar over the water-trough. About 100 cubic inches of gas may be thus obtained, from the specified quantity of the chlorate; and in a similar manner, oxygen may be procured by the distillation of nitrate of potash (saltpetre) in an earthen retort. Oxygen gas may also be obtained slowly and in small quantities, through the decomposition of water, by living vegetables exposed to the action of the sun's light. This may be demonstrated by filling an eight-ounce phial with water, and after having introduced into it a sprig of mint, inverting it in a basin of water. If this be placed in a window, or any other situation exposed to the light, minute bubbles will soon be perceived forming on the surfaces of the leaves, and gradually accumulating, they will rise to the upper part of the bottle, where after a few days a variable quantity of the gas will be collected, exhibiting, if the experiment be carefully made, a considerable degree of purity.

Oxygen gas, when pure, by whatever method obtained, is perfectly transparent, and destitute of taste or smell, exceeding atmospheric air in a slight degree in specific gravity. It is necessary for the support of animal life by respiration, and it may be breathed alone for some time with safety. Indeed, an animal confined in a small vessel, filled with this gas, will live nearly three times as long as if confined in an equal bulk of common air, and hence oxygen has been called vital air: yet it appears, that if an animal be kept in an atmosphere of oxygen gas, and obliged to breathe it for a long time, great excitement will be produced, inflammatory action will take place, and death frequently follow. Hence this gas, though a powerful supporter of life in the diluted state in which it is found in atmospheric air, cannot be used alone with safety, except for a very short period. It is absorbed by water only in a minute proportion, and therefore is usually collected in jars over that fluid. It does not, like acids or alkalies, alter the colour of paper tinged with tincture of litmus or syrup of violets, nor does it render lime-water turbid.

The most important effects of oxygen are those which arise from its powerful influence as a supporter of combustion. All inflammable bodies burn in this gas, with a greater display of heat and light than in atmospheric air. Several interesting experiments to illustrate this principle may be made by including oxygen gas in a strong glass bottle, closely stopped with a cork, having a piece of wire passed through it. If the cork be removed, and a wax taper lighted and just blown out be quickly introduced into the bottle, it will be immediately rekindled, and burn with a large, vivid flame. A sulphur match, just lighted, and held in the bottle of gas, will also burn brilliantly, with a beautiful purple colour. A piece of charcoal fixed to the wire, and made red-hot, if immersed in the gas, will burn with great splendour, throwing off beautiful sparks. A bit of phosphorus about the size of a pea may be stuck on the wire, and if then kindled and immediately plunged in the gas, it will burn with the most intense light, the splendour of which is painful to the eye. But one of the most striking instances of combustion in oxygen is that of iron wire. For the purpose of this experiment, a large jar should be used, filled with very pure oxygen gas, and placed over water in a shallow dish. A small coil is to be formed by twining a thin piece of iron wire, such as an annealed watch-spring, or small harpsichord wire, round the stem of a tobacco-pipe, and then fixing it to a cork float, the extremity of the wire being dipped in melted sulphur, and ignited, is to be introduced under the jar, when the iron will burn with a brilliant light, throwing off scintillations like fireworks.

In all the experiments above described, and other cases of the combustion of inflammable bodies in oxygen gas, combinations take place between the oxygen and the combustible, and new products arise possessing peculiar properties. The heat and light given out in these cases, if considered as depending on the presence of certain ethereal imponderable fluids, may be supposed to have been previously combined with the oxygen, and thus the gas may be conceived to consist of a ponderable basis, combined with heat or caloric and light, the evolution of which takes place on the union of the basis with the combustible body. Hence when experiments of this nature are executed with due care and accuracy, the product of combustion ought to be exactly equal in weight to the joint quantities of oxygen gas and combustible matter, which enter into its composition; and this is found to be the case. Thus when phosphorus is burned in oxygen gas, a white flaky substance will be obtained, which is phosphoric acid; and its weight will be that of the phosphorus consumed, added to that of the gas which it has absorbed. So in burning iron wire, a combination will be produced of the iron with oxygen, forming a metallic oxide, the weight of which will be equal to that of its component parts added together.

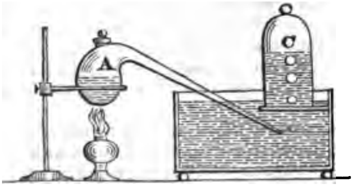
The products of the combustion of bodies in oxygen gas may be either gaseous, liquid, or solid, according to circumstances: but, considered as chemical compounds, all the combinations of oxygen with other bodies may be arranged in two classes, namely Oxides and Acids. Both these classes of compounds include varieties, depending on the different proportions of oxygen, united respectively with the several metallic and other substances which enter into their composition. Thus with iron, oxygen forms two different oxides, called from their colours red oxide and black oxide; but the former, as containing the smallest quantity of oxygen, is more properly called the protoxide of iron; and the latter, in which it contains the largest quantity, is called the peroxide. With some bodies oxygen forms three or more oxides; to distinguish which have been introduced the terms deutoxide, or second oxide; tritoxide, or third oxide, &c. Some bodies form oxides alone with oxygen, others acids only; but there are many which form both oxides and acids. The relative quantity of oxygen in this last kind of combination is, as already stated, greater in the acids than in the oxides. When a body forms two acids with oxygen, that which contains the smaller quantity is designated by a term ending in the syllable *ous*, and that containing the larger quantity receives a name ending in *ic*: thus we have sulphurous and sulphuric acids. When oxygen combines with any substance in more than two proportions to form acids, the term *hypo* is prefixed, to distinguish an acid with an inferior quantity of oxygen: thus hyposulphurous acid contains a smaller proportion of oxygen than sulphurous acid, and hyposulphuric acid less than sulphuric.

The salts formed by the combination of acids and oxides are also distinguished by the terminations of their names: thus those produced by acids with names ending in *ous* are distinguished by the termination *ite*, as sulphite of potash; and salts formed by acids with the termination *ic*, have names terminating in *ate*, as sulphate of potash. This method of nomenclature has been extended to other compounds besides those of oxygen: thus the combinations of chlorine, which are not acid, are called chlorides; those of iodine, iodides; and those of fluorine, fluorides: and their acids, and the salts which they form, are designated in an analogous manner, as hydrochloric acid, hydriodic acid, hydrofluoric acid, hydrochlorate of ammonia, &c. The compounds formed by simple combustible bodies, as those of sulphur, carbon, and phosphorus, with each other, or with metals, are distinguished by the termination *uret*, as phosphuret of carbon, sulphuret of iron, &c. The terms of *bi*-phosphuret, *bi*-carburet, &c., are used to denote compounds containing twice as much phosphorus, carbon, &c., as a phosphuret or a carburet.

Chlorine.

This is a permanently elastic or gaseous fluid, at the common temperatures and pressures of the atmosphere. But Mr. Faraday ascertained that this gas, when subjected in the nascent state to a degree of pressure equal to about four atmospheres, at the temperature of 60°, becomes condensed into a liquid.* Chlorine gas has a greenish-yellow colour, and a pungent, disagreeable odour; and it proves highly deleterious when respired.

It may be obtained from the decomposition of its compounds, the most common of which is marine or culinary salt, formerly termed by chemists muriate of soda, but which is now known to consist of chlorine united with sodium or the metallic basis of soda, and is therefore called chloride of sodium. Its decomposition may be conveniently effected by means of the apparatus represented in the annexed diagram. Mix one part of black oxide of manganese with three parts of common salt, both finely powdered, and having introduced the mixture into the tubulated retort A, pour over it two parts by weight of sulphuric acid, diluted with an equal weight of water; then pass the beak of the retort under the inverted glass jar C, filled with warm water. Now on lighting the lamp beneath the retort its contents will become gradually heated, and the sulphuric acid acting upon the manganese, which is in the state of a peroxide, will expel a part of its oxygen and reduce it to a protoxide; the liberated oxygen will then decompose the chloride of sodium, combining with its metallic basis, while the chlorine, set free, in the gaseous state, will be driven off and carried into the inverted jar, rising in bubbles through the water. The sulphuric acid will unite with the oxide of sodium (soda) as fast as it is formed, and



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* See Abstracts of Papers in Philos. Trans., vol. ii. p. 190.

thus the decomposition of the chloride is more readily effected. Chlorine gas may in like manner be procured from the decomposition of muriatic or hydrochloric acid, by means of the peroxide of manganese.

Water at the temperature of about 60° absorbs twice its volume of this gas. It should therefore be collected over warm water, which absorbs it but sparingly; or it may be received in a bottle filled with atmospheric air, by making use of a tube which passes nearly to the bottom of the bottle, and the chlorine gas as it is driven over, being heavier than common air, will gradually expel it and fill the bottle, exhibiting its peculiar green colour. The specific gravity of this gas, compared with common air, is 2.47, or about 2½ times the weight of atmospheric air.*

Chlorine undergoes no alteration when exposed to a high temperature; and even the intense heat produced by a Voltaic battery does not effect any change of the properties of this gas. When a burning taper is plunged into a bottle of chlorine gas, its flame assumes a dull red colour, a dense, black smoke, containing much carbon, is given off, and after the combustion has thus continued a short time, the taper becomes extinguished. Phosphorus, and several of the metals in a divided state, as tin, copper, and zinc, are spontaneously ignited by this gas, and burn in it brilliantly.

Chlorine and oxygen have but a weak affinity for each other; but they may be made to combine by indirect means, so as to form at least four distinct compounds. The *Protoxide of Chlorine*, containing 36 parts of chlorine and 8 of oxygen, or one combining atom of each, was discovered by Sir H. Davy, who gave it the name of Euchlorine, from its peculiar deep yellowish-green hue. It may be obtained by heating slowly in a glass retort 2 parts of the salt called chlorate of potash (formerly oxymuriate of potash), with one part of muriatic acid, when the protoxide will pass over in the state of gas, and may be collected over mercury, in an inverted jar. The retort should be heated by means of a water-bath, as the gas is very readily exploded. It differs much in its properties from chlorine, being of a deeper colour, and having an odour somewhat resembling that of burnt sugar. Water dissolves about ten times its volume of this gas, which imparts to the liquid its peculiar smell and colour. It does not act upon mercury. Vegetable colours in general are destroyed when exposed to it, some of the blues becoming reddened before the tint is obliterated. When it is detonated with hydrogen, by passing through the mixture of these gases the electric spark, it becomes decomposed, forming water and muriatic acid.

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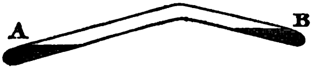
* See Book of Science, pt. i. pp. 151, 152, for the specific gravities of several of the gases relatively to that of water.

Peroxide of Chlorine is a compound of one equivalent of chlorine and four of oxygen (or 36 Ch. + 32 Ox.) It is a gaseous body, which may be procured by mixing 50 or 60 grains of chlorate of potash with a small quantity of concentrated sulphuric acid, so as to form a paste, and exposing it in a small retort to the heat of a water-bath, which must be carefully kept below the boiling point. The gas which is evolved, when collected over mercury, exhibits a deeper colour and a more aromatic odour than the protoxide. It is rapidly absorbed by water, forming a yellow solution, with a strongly astringent, disagreeable taste, but no acidity. It bleaches vegetable blues, without reddening them. When heated, it explodes violently, at a temperature above 114°, with an increase of volume amounting to one-half, oxygen and chlorine gases being produced. Mr. Faraday succeeded in condensing this gas to the liquid state, by exposing it to pressure at a temperature 32° below the freezing-point of water. Peroxide of chlorine was discovered by Sir H. Davy in 1815, and about the same time by Count Von Stadion.

Chloric Acid is that compound which enters into combination with potash to form the chlorate of potash, already mentioned. This acid may be produced by passing a current of chlorine gas through a mixture of oxide of silver and water, part of the chlorine combining with the metal to form chloride of silver, and part uniting with the oxygen of the decomposed oxide to constitute the chloric acid. The chloride, which is insoluble, is then to be separated by filtering, and the excess of chlorine contained in the liquid being expelled by heat, the acid will be obtained in the state of an aqueous solution. Chlorate of barytes, when decomposed by sulphuric acid, also yields chloric acid. When concentrated by evaporation, this acid is an oily fluid, transparent, colourless, and having a sour, astringent taste; reddening vegetable blues, and uniting with various bases to form salts. It is decomposed by the muriatic and sulphurous acids, and also by the hydrosulphuric or sulphuretted hydrogen; but not by those acids which contain large proportions of oxygen. It appears to be composed of one atom of chlorine and five of oxygen (36 Ch. + 40 Ox.)

Perchloric Acid, discovered by Count Von Stadion, probably consists of one equivalent of chlorine with seven of oxygen; but its constitution and properties have not yet been accurately investigated. It has been obtained in the form of a dense, colourless liquid, in which it is united with water, neither this nor the chloric acid apparently being capable of existing in an insulated state.

Chlorine forms a combination with water, which has been termed *Hydrate of Chlorine*. If a small quantity of water be introduced into a retort or bottle with chlorine gas, and the vessel be kept a few days in a dark place, where the temperature does not rise above the freezing point, this compound will be obtained in the state of a mass of prismatic and acicular crystals, with water adhering, which may be separated by blotting-paper previously cooled to prevent the crystals from melting. The crystalline hydrate is of a pale yellow colour, and very volatile. If a small portion of these crystals carefully dried be introduced into a bent tube, as in the annexed figure, the hydrate may be sublimed by applying a gentle heat to one end, and at the same time cooling the other. Thus if the extremity of the tube A, in which the crystals are contained, is immersed in water heated to about 90°, they will be decomposed, forming two distinct fluids, the upper consisting of a saturated solution of chlorine in water, and the lower of condensed chlorine, in the state of a dark, oily body. When the other extremity of the tube, B, is cooled, the chlorine will distil over. If the tube be again cooled to 70°, the chlorine and water will reunite to form fresh crystals.



Iodine.

This substance was first discovered in kelp, or the coarse alkaline matter procured from the ashes of marine plants. In its chemical properties, it resembles chlorine and bromine; and like those bodies, it is supposed to be an elementary substance, having never yet been decomposed. The name Iodine was given it by M. Gay Lussac, from the Greek Ἰώδης, like a violet, in allusion to its colour when in the state of gas. Iodine may be procured by various processes. After the extraction of soda from kelp for the use of the soap-boilers, a brown liquid remains, which must be subjected to a heat of about 230°, then saturated with sulphuric acid, diluted with its own bulk of water, and pouring off the liquor when cold from the crystals which will be formed, consisting chiefly of sulphate of soda, it is to be filtered, and to every twelve ounces must be added 1000 grains of black oxide of manganese in powder: this mixture being put into a glass globe, or large matrass, to which another is to be adapted; the former must be heated with charcoal, and the iodine will then pass over, in beautiful violet-coloured vapours, which will be condensed in crystalline plates, having the colour and lustre of plumbago. Iodine thus obtained is, at the ordinary temperature of the atmosphere, a soft, friable solid, which may be easily reduced to a fine powder. Its specific gravity is 4.946. It differs from metals in being a non-conductor of electricity. If passed through a red-hot tube, either alone or over charcoal, it undergoes no change. Applied to the skin, it occasions a yellow stain; and it has a hot, acrid taste, and an odour resembling that of diluted chlorine. Taken internally in a considerable quantity it is poisonous, but it has been used in medicine in small doses; and there is reason to believe, that burnt sponge, employed as a remedy for bronchocele, owes its efficacy to the iodine which it contains.

Iodine is very volatile, rising in vapour at a temperature of from 60° to 80°, and very freely at higher temperatures, boiling rapidly at 350°. Its specific gravity, in the gaseous state, is to that of atmospheric air as 8.7011 to 1; so that it is by much the heaviest of all elastic fluids yet known. This vapour is 124 times the weight of hydrogen, and as it combines with that body in equal volumes, the number 124 has been taken as the equivalent or combining weight of iodine. It renders vegetable colours yellow, and forms with water a yellow solution, though but a very minute portion of it is taken up by that fluid. It is much more soluble in ether or spirit of wine, with which it forms deep-brown solutions. This substance has the peculiar property of forming with starch an insoluble compound of a deep blue or violet colour; and hence starch has been used with advantage as a delicate test of the presence of iodine.

With oxygen iodine enters into combination, forming *Iodic* or *Oxiodic Acid*. This acid may be produced by adding chlorate of potash and hydrochloric or muriatic acid to iodine; and exposing the mixture to a gentle heat, two new compounds will thus be formed, namely, chloriodic acid and oxiodic acid. By the application of greater heat, the former may be driven off, and the oxiodic acid will be left pure. The oxygenation of iodine may be also effected by heating that substance repeatedly in nitric acid. The iodic acid is a white, semi-transparent, deliquescent solid, having a sour taste, but no smell. Its specific gravity exceeds 2, and it consists of 1 proportional of iodine, and 5 of oxygen, so that its equivalent number is $124 + 40 = 164$. Its aqueous solution reddens, and then destroys vegetable colours. When mixed with charcoal, sugar, sulphur, and other combustible substances, it detonates on the application of heat.

It has been stated, that the solution of this acid corrodes all the metals, and even acts on gold and platina; but Mr. Connell, who procured it by means of the nitric acid, confirms the observation of Serullas, that it does not attack gold; and adds, that it is equally inert with respect to platina, and that iron filings thrown into the acid solution caused no effervescence; but when the liquid was boiled, a white powder was precipitated.*

Iodine is capable of union with chlorine, forming a compound called *Chloriodic Acid*, discovered about the same time by Sir H. Davy and M. Gay Lussac. This acid makes its appearance, as already stated, during the process for obtaining iodic acid from chlorate of potash and muriatic acid; but it may be procured from the direct union of its constituents. Thus on passing a current of chlorine gas into a vessel containing iodine, the gas is quickly absorbed; and the result will be a substance, colourless when the two bodies combine in proper proportions, red or brown when there is an excess of iodine, and yellow if there be an excess of chlorine. It is volatile, and may be sublimed without decomposition. It is deliquescent, and dissolves readily in water, forming an acid solution, which destroys vegetable blues. The salifiable bases, when presented to this acid, in solution, decompose it, and iodic and muriatic acids are produced. It is said likewise to be decomposed by mercury.

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* See Jameson's Journal of Science for 1831.

Bromine.

This is among the most recently discovered of the simple substances. It is commonly procured from the uncrystallizable liquid, called Bittern, which remains after the manufacture of sea-salt. If a current of chlorine gas be passed through this liquid, it assumes an orange tint, and yields a peculiar disagreeable smell, arising from the evolution of Bromine;[*] a portion of sulphuric ether is then to be agitated with it, and on being allowed to stand, it will separate from the water, together with the bromine, which gives it a reddish-brown colour. The ethereal solution must be shaken with a solution of caustic potash, when bromate of potassa and bromide of potassium will both be formed. The latter of these salts being obtained in cubic crystals by evaporation, is to be decomposed by a solution of chlorine in water; and the bromine, which is volatile, may be separated by distillation, and obtained in a receiver, kept cool by covering it with ice.

At common temperatures bromine is a liquid; at about 10° below zero, Fahrenheit, it becomes congealed into a crystalline, foliated mass; and at 116° it boils. It is about three times the weight of water. The liquid has a deep, dull, red colour,[†] and a peculiarly unpleasant suffocating odour; and its taste is also strong and nauseous. It corrodes the skin, and stains it of a yellow colour; and it must also be remarked, that it is a powerful and dangerous poison. It dissolves but sparingly in water, more easily in alcohol, and most readily in ether. Vegetable colours, as litmus and even indigo, are destroyed by it. A burning taper plunged in its vapour quickly becomes extinguished, the flame previously assuming a reddish tint. Phosphorus inflames spontaneously in its vapour. Tin and antimony likewise take fire in it; and potassium introduced into it explodes with violence. In its general mode of action it resembles chlorine and iodine, being reckoned a supporter of combustion.

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[*] Bromine derives its appellation from its nauseous flavour, Βρῶμος, its Greek etymon, signifying a *stench*.

[†] "Liquid bromine, when viewed in thin portions or small drops, displays a hyacinthine red hue (red with a tinge of yellow); in larger masses, the colour becomes so intense that it appears opaque and black."—*Mitscherlich's Introd. to Chem.*, vol. i. p. 70.

With oxygen it forms a compound called *Bromic Acid*, which may be obtained by adding sulphuric acid to the combination of this acid with barytes (bromate of barytes); and sulphate of barytes being thus formed, when the whole of that salt is precipitated, the bromic acid will remain in solution, and may be concentrated by slow evaporation. It cannot, however, be entirely deprived of water, as it is partially decomposed at a high temperature. The acid solution has very little smell, but possesses a sour taste, and it first reddens and then destroys the blue colour of litmus.

The specific gravity of the vapour of bromine and its atomic weight, are uncertain, being variously stated by different experimentalists. According to Berzelius, the combining weight of this body is 78.26; but 75 is the number generally adopted. Hence bromic acid, containing 1 atom of bromine with 5 of oxygen, its equivalent number will be $75 + 40 = 115$.

Bromine unites with chlorine, when a current of the latter is passed through the liquid bromine, and the vapours which arise at a low temperature may be obtained by condensation in the form of a reddish-yellow liquid called *Chloride of Bromine*. It has a very penetrating odour, and disagreeable taste. It is extremely volatile; and metals reduced to fine powder take fire in its vapour. The solution of chloride of bromine in water acts powerfully in bleaching vegetable substances.

Bromine unites also with iodine, hydrogen, sulphur, phosphorus, and selenium; as well as with many of the metals, forming compounds called bromides.

Fluorine.

This body, though from the analogy of its mode of action, when in combination with other substances, to that of oxygen and chlorine, it is supposed, like them, to be a simple or elementary body, has yet never been obtained in a separate state, on account of the difficulty, or rather impossibility, of keeping it uncombined in vessels of any known substance whatever. Its compounds are not of common occurrence, except the mineral called fluor spar, which appears to be a compound of fluorine with calcium, or the metal of lime; and it only occurs in a few other mineral substances. The fluoride of calcium (fluor spar.) may be decomposed without difficulty; but the fluorine is no sooner extricated, than it enters into union with some other body. One of the compounds which it readily forms is with hydrogen, constituting *Hydrofluoric Acid*, which may be thus procured: Let fluor spar, finely powdered, and mixed with twice its weight of strong liquid sulphuric acid, be distilled by a moderate heat in a silver or leaden retort, to which should be adapted a silver tube and receiver, the latter of which must be kept cool during the operation, by immersing it in a mixture of pounded ice or snow, and salt. The hydrofluoric acid will then pass over in the form of a very volatile liquid, but having the appearance of sulphuric acid. It is best preserved in bottles of silver or lead, with well-fitted stoppers of the same metal. Its specific gravity is 1.06, but it becomes increased in density by the addition of water to 1.25, affording a singular instance of fluid condensation. It has a strong attraction for water, beyond that of sulphuric acid; and great heat is evolved when it is dropped into water. As it is extremely volatile, the utmost care should be taken in making experiments, to avoid inhaling its vapour, the irritating effects of which are extremely injurious; and the liquid acid itself acts as a powerful caustic when dropped on the skin. Among the most curious and important properties of this acid is its action on glass, which it deeply corrodes, in consequence of its affinity for the basis of the siliceous earth contained in the glass, with which it forms a new compound called *Silicofluoric Acid*. Thus it decomposes glass, and hence destroys the transparency of glass vessels or plates with which it comes in contact. This property of the acid has been ingeniously applied to the purpose of making engravings or etchings on glass. These are executed in a manner analogous to etchings on copper with aqua fortis. Plates of glass, coated with bees' wax and turpentine melted together, may have figures traced on them with an etching needle; after which they may be covered with the diluted acid, or exposed to its vapour, when on removing the coating, the figures will be found delineated on the glass.

Attempts have been made to procure fluorine in a separate state, by decomposing its compounds by means of Galvanism, or by the more usual operations of chemical analysis; and in both cases the object has been frustrated by the impossibility of preventing the nascent element from forming immediately new compounds. When hydrofluoric acid is acted on by a Galvanic pile, inflammable gas will be given off at the wire connected with the negative pole, and the opposite wire of platina will become corroded and covered with a chocolate-coloured powder, which appears to be fluoride of platina. The combination of fluorine with silver (fluoride of silver) may be decomposed by means of chlorine, which unites with the silver; but the fluorine cannot thus be obtained in a separate state. For when fluoride of silver is placed in a glass retort, and chlorine is added, the fluorine will be extricated; but it immediately decomposes the siliceous earth of the glass, and enters into union with its basis called silicon, with which it forms silicofluoric acid. If the decomposition be effected in a vessel of platina, fluoride of platina, the substance already mentioned, will be formed; and if a retort of lead or any other metal be used, the fluorine will combine with it, unless water be present, which it decomposes to form hydrofluoric acid, previously described. Besides the compounds already mentioned, fluorine unites with boron, the basis of boracic acid, with which it constitutes borofluoric acid, or as it has been also called, fluoride of boron. It also unites with sulphur and phosphorus; but these compounds have been but lately discovered. No combinations have yet been obtained of fluorine with oxygen, chlorine, iodine, bromine, carbon, or nitrogen.

Hydrogen.

Hydrogen is one of the most important among the inflammable substances, being abundantly diffused throughout nature in various states of combination. Its distinct existence as a peculiar kind of matter, was first ascertained by Mr. Cavendish, in 1766. The specific gravity of hydrogen gas being less than that of any other substance with which we are acquainted, it seems to possess a strong claim to the title of a simple or uncompounded body. The weight of 100 cubic inches of hydrogen gas is less than three grains, while the same bulk of atmospheric air will weigh thirty-one grains. The comparative levity of this elastic fluid gave rise to its employment for the inflation of air-balloons.

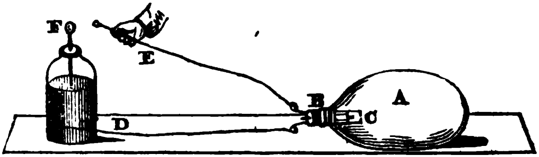
Hydrogen gas, when pure, is perfectly transparent. It is, however, usually mixed with certain adventitious matters, which communicate to it a very unpleasant smell, but when these are separated, it appears to be completely inodorous. It possesses no taste. Hydrogen gas will not serve for the respiration of animals, though it does not, like some gases, prove immediately deleterious to those who breathe it; and, when largely mingled with atmospheric air, it may be respired with safety. Vegetables grow and flourish when confined in this gas.

Hydrogen gas is extremely inflammable, readily burning when in contact with oxygen gas or atmospheric air. The produce of this combustion is water, which is formed and decomposed by many processes, natural and artificial.

The most usual method of obtaining hydrogen gas for the inflation of balloons, or for chemical experiments, is by adding sulphuric acid to a mixture of zinc or iron filings with water. The metal in this case, assisted by the acid, attracts the oxygen of the water, and its hydrogen is set free, and may be collected for use by means of a proper apparatus. Hydrogen gas may be also procured from water by electricity. Thus water inclosed in a glass tube, may be decomposed by passing through it a current of electric sparks. It may also be separated into its constituent parts, by exposing it to the action of a Galvanic battery.

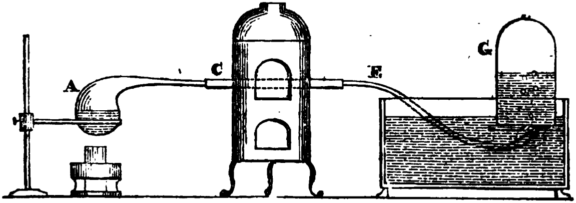
Though hydrogen may be made to burn when mixed with oxygen, atmospheric air, and other supporters of combustion, it extinguishes a lighted taper, or any burning body immersed in it. It may, as already stated, be breathed with safety for a short time, though it will not support animal life. If the lungs be filled with it by inhaling a few times this gas from a bladder, or a bag of oiled silk, a peculiar effect is produced on the voice, which is rendered much shriller than usual, but its influence is only temporary.

Protoxide of Hydrogen.—Hydrogen combines with several other simple substances, and especially with the supporters of combustion, forming many important compounds. With oxygen it is found to unite in two proportions. When two volumes, or parts by measure, of hydrogen gas, are mixed with one volume, or measure, of pure oxygen gas, in a glass globe, or any other receptacle previously exhausted of air, the gases being inflamed by the electric spark, will combine with the extrication of light and heat; and the interior of the globe will become lined with drops like dew, which being collected and weighed, will be found to consist of pure water, equal in weight to that of the gases which have disappeared. There are many modes of making this experiment, among which may be mentioned the following, as being easily practicable, with the assistance of an electrical machine:



A very large bladder, A, is to be filled with oxygen and hydrogen gases, in the proportions just mentioned. To the opening must be fitted a sound cork, B, with a short glass tube passed through it, by means of which the gases may be introduced into it; and on each side of the tube brass wires are to be passed through the cork, so that their ends may project a little way within the bladder at C, where they are to be brought within about an inch of each other. To the ends of the wires without the bladder, are to be attached two other wires, D E, from twenty to thirty feet in length. One of these wires, D, is to be brought in contact with the outside of an electrical jar; and the other wire, E, to be advanced within an inch of the brass knob, F, of the same jar; then on charging the jar by means of an electrical machine, when it has been sufficiently excited, a discharge will take place, the spark passing from the knob, F, through the wire, E, and another spark will pass between the wires within the bladder at C, which will occasion an explosion of the gases, and the production of water, which however will be liable to be dissipated by the bursting of the bladder. If there be an excess, in the mixture, of either of the gases, they will still only unite in the ratio already stated, and the superfluous gas will remain in an uncombined state. The production of water by the union of oxygen and hydrogen gases, may be exhibited by simply burning a jet of hydrogen gas, from a bladder with a stop-cock, under a bell-glass, including atmospheric air; and, as the combustion proceeds, water will be formed, which condensing on the inner surface of the glass will trickle down its sides.

The composition of water is shown by analysis, in the experiments already mentioned relative to the production of hydrogen gas.



Water may also be decomposed in consequence of the affinity of iron for oxygen at a high temperature. Let an open gun-barrel, C, in the preceding figure, be filled towards the centre with iron turnings; and to one end of it must be luted a small retort, A, containing water; and to the other end a bent tube, F, terminating under a gas-holder, or an inverted glass jar, filled with water, G. The gun-barrel passing across a furnace, or a large chafing-dish, is to be heated by means of charcoal; and when it is red-hot, the water of the retort must be made to boil, by placing under it a small lamp, and the steam passing over the red-hot iron will be decomposed; its oxygen will unite with the iron, and the hydrogen thus set free, will pass through the tube, E, and be collected under the bell-glass, G. If this experiment be carefully made, by using a compact porcelain, or glass tube, instead of the gun-barrel, and weighing the iron before and after the operation, it will be found to have gained exactly as much as, added to the gas produced, will be equal to the weight of the water consumed. Hence it will appear, that water consists of eight parts by weight of oxygen, and one of hydrogen.

Water may also be decomposed by means of the Galvanic or Voltaic battery, and by various other methods; but in whatever manner it be examined, it will be found to consist of the same proportions, namely, one volume of oxygen, and two volumes of hydrogen; or, eight parts by weight of oxygen, and one of hydrogen. Hence it follows, that oxygen gas must be sixteen times the weight of hydrogen gas: therefore, this fluid may be supposed to consist of one atom of hydrogen, having only the eighth part of the weight of an atom of oxygen, and the combining number of which will therefore be 1; and one atom of oxygen, the combining number of which must be 8; so that the combining or proportional number of water will be 9, the sum of the numbers of its constituent parts.

Oxygen and hydrogen will also combine in the proportion of equal masses of each gas. This compound, which has been called *Deutoxide* or *Peroxide of Hydrogen*, was discovered in July, 1818, by M. Thenard, who procured it by the addition of peroxide of baryum and muriatic acid to water, and afterwards precipitating the resulting protoxide of baryum with sulphuric acid; the excess of oxygen in the peroxide entering into combination with the water, and thus converting it into oxygenated water, or peroxide of hydrogen. But other additions and repeated manipulations are requisite to separate the muriatic acid from the oxygenated water, and obtain the latter in a pure state, the process being altogether complicated and troublesome.* Peroxide of hydrogen thus prepared, is a colourless syrup-like substance, of the specific gravity of about 1.45. It is nearly destitute of smell, destroys vegetable blue colours, and bleaches the skin, on which it acts as a caustic when the application is continued. It rises in vapour, even at low temperatures, and cannot be congealed by cold. At 58° of Fahrenheit it becomes decomposed, oxygen gas being given off in abundance, and at the heat of boiling water it explodes. It is decomposed by all the metals, except iron, tin, antimony, and tellurium. The metals should be powdered, or otherwise finely divided; and with some of them, as silver, gold, and platina, the decomposition takes place, with the evolution of light and heat.

Among the most important compounds of hydrogen, is that which it forms with chlorine, constituting the powerful acid commonly called *Muriatic Acid*, and sometimes *Hydrochloric Acid*. Under the former appellation, it has long been known, and also under that of Spirit of Salt, being obtained from the decomposition of common or marine salt. In this state it is a liquid, being combined with water; but it may also be obtained alone, in the form of gas, and the mode of procuring it was first described by Mr. Cavendish, in 1766. It was supposed that muriatic acid, like the nitric, sulphuric, and many others, consisted of oxygen combined with some acidifiable base, and in pursuance of that notion various attempts were made to decompose it, all which proved more or less unsatisfactory. At length it was ascertained, through the experiments of Sir H. Davy in England, and of Gay Lussac and Thenard in France, that muriatic acid gas, when pure, may be separated into hydrogen and chlorine, and that consequently oxygen does not enter into its composition. Hence it appears that Scheele—(who discovered chlorine, and obtained it, by separating from it the hydrogen with which it is united in muriatic acid, and which he therefore supposed to be a compound of hydrogen with the newly-obtained gas),—formed a correct conclusion.

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* For an account of the mode of obtaining this body, see Journ. of Science, ed. at R. I., vol. iii. pp. 115—120; or, Brande's Manual of Chemistry, vol. i. pp. 457—459.

If chlorine and hydrogen in equal quantities by measure be mixed together, and exploded by the electric spark, or a burning match, muriatic acid will be formed; and if the experiment be properly conducted, the quantity of acid, or compound gas obtained, will be exactly equal to that of both the constituent gases taken together. Thus, if 50 cubic inches of chlorine, and as many of hydrogen be exploded by electricity, 100 cubic inches of muriatic acid will be obtained; and as the weight of chlorine is to that of hydrogen as 36 to 1, their combining or proportional numbers must be in the same ratio, and the combining number of muriatic acid will consequently be 37. Muriatic acid gas is colourless, and has an intensely acid taste, and a peculiar pungent smell. It cannot be respired, and it is incombustible, extinguishing burning bodies plunged into it. Like other acids it reddens vegetable blues, as litmus paper; but turmeric paper exposed to it acquires a brown tint, not unlike that produced by an alkali. The attraction of this gas for water is very great, so that it immediately forms fumes like white clouds, when suffered to escape into the air, by combining with the water contained in it. Water at the temperature of 40°, absorbs 480 times its own bulk of muriatic acid gas, being at the same time increased in quantity. The solution forms common muriatic acid, which when pure is colourless, and possesses all the general properties of the gas. Its specific gravity varies according to the quantity of the gas with which the water is combined; but it is usually about 1.16 or 1.17.

Muriatic acid is commonly procured from the decomposition of common salt, by means of sulphuric acid diluted. In this case a double decomposition takes place. The salt, which is a compound of chlorine, with the metal sodium (the basis of soda), being introduced into a tubulated retort, on adding to it sulphuric acid, and applying heat, the water mixed with the acid becomes decomposed, and its oxygen uniting with the sodium, forms soda, which combines with the sulphuric acid, while the hydrogen of the water unites with the chlorine thus set free, to form muriatic or hydrochloric acid. If the operation be conducted over mercury, the gas will be obtained in great purity, though not free from water. A process very similar to this is usually adopted for procuring liquid muriatic acid; the gaseous acid as it is produced, being condensed in a series of bottles, each containing a small quantity of water, and provided with safety tubes.

Hydrogen and iodine, placed in contact, combine slowly at a moderate temperature, but the union more readily takes place when iodine is heated in hydrogen gas; an acid gas being formed, which is rapidly absorbed by water, and which is decomposed by mercury, and therefore cannot be preserved long over that fluid. This gaseous product is called *Hydriodic Acid*. There are various modes of preparing it, one of the most convenient of which is by exposing eight parts of iodine and one of phosphorus, moistened with water, in a small retort, to a gentle heat, when the gas will be evolved, and must be received over mercury, but transferred as quickly as possible into an exhausted vessel, or it may be allowed to pass over into a bottle filled with atmospheric air, in the manner directed for procuring chlorine gas;* both these gases, from their superior specific gravity, being capable of expelling common air in a great measure from an open vessel when poured into it.

Hydriodic acid is a colourless elastic fluid, having a sour taste, reddening vegetable blues, and exhaling an odour like that of muriatic acid, white fumes escaping when it is exposed to the atmosphere. Its specific gravity is 4.34, that of atmospheric air being 1; and 100 cubic inches weighing 133.4 grains. A saturated solution of hydriodic gas may be obtained by careful evaporation of water impregnated with it, by passing sulphuretted hydrogen through a mixture of iodine and water. The liquid acid has a specific gravity of 1.7. It dissolves iodine, acquiring a deep brown colour, and it is decomposed by the nitric and sulphuric acids. The acid in its gaseous state is decomposed by chlorine, muriatic acid being formed, and the iodine set free, forming violet-coloured fumes, when the chlorine is mixed with atmospheric air. From the action of mercury, and some other metals, on hydriodic acid gas, causing the evolution of half its volume of hydrogen, it may be inferred that this acid is composed of 1 equivalent of each of its constituents, and therefore its combining number must be $124 + 1 = 125$.

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* See p. 76.

Hydrogen and bromine do not enter into combination, when the vapour of the latter is mingled with the former, and exposed to the light of the sun; but the mixture may be inflamed by introducing into it a lighted match, or red-hot iron, when union takes place, but without explosion. The product is a colourless gas, which, from its properties, has been styled *Hydrobromic Acid*. It may also be procured from the decomposition of water, by means of bromine and phosphorus, in a mode analogous to that in which hydriodic acid is obtained.

The hydrobromic acid gas is rapidly absorbed by water, but may be preserved over mercury. Its aqueous solution is at first colourless, but it readily dissolves bromine, and receives from it a yellow tint. It is decomposed by chlorine, and likewise by nitric acid, but not so easily by the sulphuric acid. In the mode of its composition it resembles the hydriodic acid, and may be supposed to consist of 1 atom of bromine and 1 of hydrogen, so that its combining number will be $75 + 1 = 76$.

Hydrogen combines with fluorine to form the compound called *Hydrofluoric Acid*, the properties and method of procuring which have been already described.* Fluorine having never been obtained in a separate state, its equivalent or combining number cannot readily be ascertained. It has been variously estimated, from 16 to 19; and since hydrofluoric acid may be regarded as bearing an analogy of constitution to the other hydrogen acids, it must be considered as composed of 1 atom of fluorine and 1 of hydrogen, and if 19 be taken as the atomic weight of the former, that of the latter must consequently be $19 + 1 = 20$.

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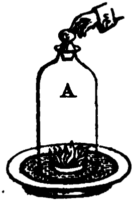
* See p. 83.

Hydrogen forms compounds with a few only of the electro-positive bodies, as nitrogen, sulphur, phosphorus, arsenic, and tellurium; and the most important of these combinations will be subsequently described. In some respects hydrogen, in a variety of chemical operations, appears to act as a sort of antagonist power to oxygen, the one exhibiting the highest degree of electro-negative energy, and the other perhaps the utmost electro-positive energy. Next to oxygen it is apparently the most widely extended and abundant of all known bodies. Like oxygen, also, it forms, in combination with other elements, three sorts of compounds: thus, with chlorine, iodine, &c., it constitutes acids; with nitrogen, ammonia, a salifiable basis; and with oxygen itself it forms water, with arsenic, arseniuretted hydrogen, neither of which bodies have acid or alkaline properties. M. Gay Lussac, in a paper published in the Annales de Chimie, for July, 1814, proposed a classification of undecomposed substances, in which hydrogen is reckoned an alkalizing principle, and nitrogen an acidifying principle; but the inconsistency of this theory has been fully demonstrated by Sir H. Davy, who very justly remarks, that "When certain properties are found to belong to a compound, we have no right to attribute these properties to any of its elements, to the exclusion of the rest, but they must be regarded as the result of combination.*

Nitrogen.



As this gas is contained in a large proportion in atmospheric air, it may be procured by burning phosphorus, in air inclosed over water, in a tall glass jar. The phosphorus may be placed in a small basin of Wedgwood ware, as in the annexed figure; and after having been inflamed with a red-hot iron, it is to be covered with the inverted jar or bell-glass, A. The jar should have an open neck at top, filled with a stopper, which must not be inserted at first, part of the air, expanded by heat, being allowed to make its escape; the stopper is then to be replaced, and the combustion suffered to continue, till the phosphorus becomes extinguished, in consequence of all the oxygen having been consumed. The remaining gas, after the jar has cooled, must be well washed with lime-water, and the product will be pure nitrogen. This gas may also be obtained by allowing atmospheric air to stand in an inverted jar, over a mixture of equal parts of iron filings and sulphur, made into a paste with water; which mixture would absorb the oxygen of the air, and leave the nitrogen behind. Another method of procuring nitrogen is by passing chlorine gas through a strong solution of ammonia in water. In this case the ammonia, which is a compound of hydrogen and nitrogen, becomes decomposed by the chlorine, which unites with its hydrogen to form muriatic acid, and the nitrogen is given out. If, however, a large proportion of chlorine be used, chloride of nitrogen will be formed.

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* Journal of Science, ed. at R. I., vol. i. p. 286.

Nitrogen, however it may be obtained, is a permanently elastic fluid, it having hitherto resisted all attempts to reduce it to the liquid state by compression and low temperature. It is a colourless gas, destitute of taste and smell, unfit for respiration, and is neither inflammable, nor capable of supporting combustion, burning bodies introduced into it becoming instantly extinguished. It has no action on vegetable colours, nor upon lime-water, and is absorbed by water only in a very minute proportion. Its weight is fourteen times that of hydrogen, and it is therefore somewhat lighter than atmospheric air.

Nitrogen enters into combination with oxygen in various proportions, forming several important chemical compounds. It is likewise, as already stated, one of the constituents of atmospheric air, which consists of this gas, mixed with oxygen, and small quantities of aqueous vapour and carbonic acid gas; but these latter bodies appear to exist, not only in comparatively minute, but also in variable quantities. The physical properties of atmospheric air have been already described and elucidated in the Treatise on Pneumatics; the notice of it here will therefore be confined to its chemical properties and modes of action.

It is now generally admitted by chemists, that though the essential constituents of atmospheric air, oxygen and nitrogen, are always found in the same proportions, yet this compound gas, in which we live and breathe, is a mere mixture of its component parts. Considered in this point of view, common air presents a wonderful uniformity in various situations. For air, collected by means of a balloon, at the distance of more than 21,000 feet above the surface of the earth, or at the level of the sea, procured from the interior of crowded towns or cities, or from the tops of high mountains, and from the equatorial, or from the polar regions of the earth, is found to contain about one part, by measure, of oxygen, and four of nitrogen. The general constitution of the atmosphere may be thus more exactly stated:

	By Measure.	By Weight.
Nitrogen	77.5	75.55
Oxygen	21.	23.32
Aqueous Vapour	1.42	1.03
Carbonic Acid	0.08	0.10
	100.	100.

Since nitrogen gas is characterized chiefly by negative properties, and is especially unfit for respiration, the purity of the atmosphere is always estimated by the quantity of oxygen gas which it contains; and hence the employment of instruments called Eudiometers, consisting in general of tubes, adapted to apparatus for absorbing or consuming the oxygen of a given quantity of air, and for measuring the residuum.

Among the chemical compounds of nitrogen and oxygen, the first is the *Protoxide of Nitrogen*, containing a larger proportion of oxygen than is found in common air, but less than in any other of the chemical compounds. This oxide, which is a gaseous body, was discovered by Dr. Priestley in 1776, and by him termed Dephlogisticated Nitrous Air; by others it has been styled Gaseous Oxide of Azote; and as elsewhere mentioned, from its effects when respired, Intoxicating Gas. It may be obtained by exposing the next compound, nitric oxide, over a mixture of sulphur and iron filings; by which the oxygen will be partially absorbed, and the protoxide formed. It may, however, be obtained more readily, and in a state of greater purity, by heating in a glass retort over a lamp the salt called nitrate of ammonia, which becomes decomposed at the temperature of about 420°, into hydrogen and protoxide of nitrogen. The gas thus obtained is destitute of colour, and has a sweet taste, and a peculiar agreeable smell. It is easily absorbed by cold water, which takes up about its own bulk of this gas, and gives it out when heated. It does not change the colour of vegetable blues. It is a supporter of combustion, and a taper introduced into it, which has been lighted and just extinguished, will be rekindled, and burn with an enlarged flame, surrounded by a purplish halo. Iron wire or charcoal, previously made red-hot, will burn in it almost as brilliantly as in oxygen gas, but for a shorter time. Phosphorus and sulphur, when introduced into it while in a state of active inflammation, burn with great violence; but if immersed in this gas while they are burning but faintly, the flame becomes extinguished. When mixed with hydrogen, the protoxide of nitrogen may be made to detonate by means of flame, or of an electric spark. Two cubic inches of the protoxide require two cubic inches of hydrogen for its decomposition; water in this case being produced, and two cubic inches of nitrogen remaining. Now, since two cubic inches of hydrogen require one cubic inch of oxygen to form water, the protoxide of nitrogen must be composed of two cubic inches, or volumes of nitrogen and one of oxygen, condensed into the space of two volumes.

The singular effect of this gas when breathed has been already mentioned. Though the temporary use of it is seldom attended with inconvenience, yet, from the great excitement it produces, it cannot be long breathed without danger. Experiments relative to its effects may be made by filling a clean bladder with some of the gas, the purity of which has been previously ascertained, and it may then be inhaled through a pipe, with a stop-cock adapted to it. Different persons are variously affected by it: with some it appears to be nearly inactive, but most persons on using it feel their spirits greatly exhilarated, as by the moderate use of wine; and upon the whole, it may be regarded as occasioning the incipient and most agreeable effects of intoxication.

The *Nitric Oxide* or *Deutoxide of Nitrogen*, though not first discovered, was first carefully examined by Dr. Priestley, who gave it the name of Nitrous Gas. It may be obtained by decomposing nitric acid by means of metals, as by pouring the acid on copper filings, in a retort, and collecting the fumes which will be produced over water. The first portions that pass over are contaminated with nitrogen and nitrous acid gas, and should therefore be rejected. Nitric oxide is a colourless, gaseous fluid, sparingly soluble in water, and not affecting the colour of vegetable blues. It is quite unfit for respiration. Most flaming bodies, as burning sulphur, are extinguished when immersed in it; but charcoal and phosphorus readily burn, if introduced into it in a state of intense ignition. It does not explode with hydrogen in any proportion, but produces a green flame, if burnt with it, in common air. When nitric oxide is mixed with oxygen gas, deep red fumes are formed, which are readily absorbed by water; and the same phenomenon takes place when this gas is mixed with the atmosphere, or with any air containing oxygen. Supposing the atomic weight of nitrogen to be 14, this oxide consisting of 1 atom of nitrogen and 2 of oxygen, its combining weight must be $14 + 16 = 30$.

Hyponitrous Acid is a compound of nitrogen and oxygen, intermediate as to nitric oxide and nitrous acid, which was discovered by Gay Lussac. It may be produced by mixing nitric oxide and oxygen over mercury, with a little concentrated solution of potash floating above it. The proper proportions are four volumes of nitric oxide and one of oxygen, which combine together and unite with the potash; from which the hyponitrous acid cannot be disengaged without decomposition.

Nitrous Acid is the next compound, which may likewise be formed by adding oxygen to the nitric oxide; this, however, must be done in an exhausted glass vessel, for the nitrous acid is absorbed both by water and by mercury. When two volumes of nitrous oxide, and one volume of oxygen, are thus mixed, heat is evolved, and the gases become condensed to one-third of their original bulk, forming nitrous acid. This gas, which becomes reduced to the liquid state at zero of Fahrenheit, is readily absorbed by water, forming an acid liquor. Nitrous acid gas supports the combustion of charcoal and phosphorus, but extinguishes burning sulphur.

Nitric Acid is a compound in which oxygen exists in the largest proportion. It is said to have been produced in a minute quantity by passing electric sparks, for a long time, through a mixture of nitrogen with oxygen; but it may be more readily obtained by passing nitric oxide very slowly into oxygen gas over water. However, the usual mode of procuring it is by the decomposition of nitre (nitrate of potash) with sulphuric acid; the latter entering into combination with the potash, and the nitric acid may be distilled over: thus procured, it contains at least one-fourth its weight of water, and is therefore called hydrated nitric acid, and popularly aqua fortis. In this state it is a transparent liquid, colourless when pure, having an intensely sour taste, and acting powerfully on animal substances, tinging the skin yellow when but lightly applied to it. It acts with great energy on most substances which have an affinity for oxygen, and which thus decompose it. When brought in contact with hydrogen, at an elevated temperature, a violent explosion takes place: the experiment therefore cannot be made without danger. If it be poured on warm, dry, pulverized charcoal, inflammation ensues; and abundant fumes of nitric oxide are given out. Inflammation may also be produced by pouring nitric acid on spirit of turpentine; but this experiment requires caution, and the best method of performing it is, by affixing the phial containing the acid to the end of a long rod, as some degree of explosion takes place. Other essential oils may also be inflamed by this acid; and with oil of amber, it forms a resinous compound, which has been called artificial musk, having an odour somewhat resembling that of musk.

Chloride of Nitrogen.—Nitrogen combines with chlorine, though their mutual affinity is inconsiderable; and therefore the compound is most readily obtained by the indirect process of passing a current of chlorine gas through a solution of any salt containing ammonia, at a temperature of about 90°. The salt best adapted for this purpose is nitrate of ammonia, or that which is obtained by the union of nitric acid with ammonia. The compound called chloride of nitrogen then appears, first in the form of an oily film on the surface of the saline solution, which collects into yellowish drops, and sinks to the bottom of the vessel. This is one of the most powerful explosive compounds with which we are acquainted; and it is, therefore, too dangerous and unmanageable to be applied to any useful purpose, and experiments made on it require the utmost care and caution. M. Dulong, who discovered it in 1812, lost an eye and the use of a finger by its explosion; and Sir H. Davy, who afterwards made experiments on it, was wounded in the face. It explodes with extreme violence at the temperature of about 200°; but the mere contact of sulphur, phosphorus, oil, and some other inflammable bodies, causes its detonation at common temperatures. The composition of chloride of nitrogen has been differently estimated by different writers. It consists, according to some, of 14 Nitr. + 108 Ch.; while others state it to be 14 Nitr. + 144 Ch.

With iodine, nitrogen forms a compound called *Iodide of Nitrogen*. It may be obtained by pouring a solution of ammonia upon a very small quantity of iodine. It is an insoluble black powder, highly explosive, as the slightest touch will sometimes cause detonation. When left exposed to the air it gradually evaporates; or if moist, becomes decomposed into nitrogen, and iodic and hydriodic acids; and it is likewise decomposed by hot water, and by alkaline solutions.

Ammonia.—Nitrogen and hydrogen may be mixed together in any proportions without combining; but indirectly they may be united, forming the gaseous compound called volatile alkali or ammonia. This appears, under certain circumstances, to be formed naturally, being found in Egypt and some other countries in combination with muriatic acid, constituting the saline substance known in the shops by the name of sal ammoniac. From this salt ammonia is most readily procured. One part of muriate of ammonia (sal ammoniac), and two parts of dried quicklime, both powdered, must be introduced into a small glass retort; and upon the application of a gentle heat, a pungent gas will be evolved, which is ammonia. It may be collected over mercury, or if collected over water, it will be rapidly absorbed by that fluid, constituting the liquor of ammonia. This alkali is at common temperatures a permanently elastic fluid; but it has been reduced to the liquid state, by means of cold and pressure, by Mr. Faraday. In this form it is a colourless, transparent liquid, of the specific gravity of 0.76; and its refractive power exceeds that of water. Ammoniacal gas is much lighter than atmospheric air; its specific gravity, compared with that of hydrogen, being as 8.5 to 1. It has a very acrid odour, which is not disagreeable when considerably diluted with common air. It cannot be respired alone, as animals instantly die when immersed in it; and burning bodies are extinguished by it. The gas itself is somewhat inflammable, for a small jet of it thrown into a jar of oxygen will burn, the products being water and hydrogen. It turns vegetable blues to green, and renders yellows brown, like other alkalies; but the effect is not permanent, for as the gas exhales the original colours return. Water, at the temperature of 50°, takes up 670 times its bulk of ammoniacal gas; becoming increased in quantity, and lowered in specific gravity. In this state the liquor of ammonia is commonly used, both for chemical and medical purposes. This liquid absorbs carbonic acid when exposed to the air, and should therefore be preserved in well-stopped glass bottles. At the heat of about 140°, ammonia is rapidly evolved from it. When concentrated, it congeals at 40°, assuming a gelatinous appearance, and losing its odour. When ice is introduced into a jar of ammoniacal gas, it melts quickly, absorbing the gas, and forming liquor of ammonia. This gas may be decomposed into its constituent parts, by passing it through a red-hot tube; and the decomposition may be hastened by filling the tube with coils of iron wire, and thus presenting to the gas a larger heated surface. The products may be received in a jar inverted over water. Dr. Henry ascertained, that a mixture of ammonia and oxygen gas might be inflamed by the electric spark. The alkaline gas also alone may be decomposed, by passing through it a succession of electrical sparks: by this process its volume becomes increased, and a cubic inch of it may be augmented to double that bulk, by passing two or three hundred charges of electricity through it. Ammonia is formed during the decomposition of many animal substances: the production of this gas also takes place in consequence of the violent action of nitric acid upon phosphorus and some other metals, and it is formed by exposing to an atmosphere of nitrogen moistened iron filings; and in certain other cases, in which the gases composing it are given off simultaneously, under peculiar circumstances.

Carbon.

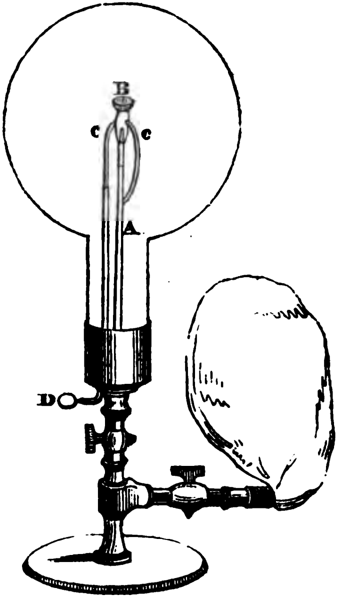
The physical properties of this substance in its usual state of aggregation, as procured from the distillation of animal and vegetable substances, are too well known to require a particular description. This body may be obtained in the state of charcoal, fot experimental purposes, by covering pieces of wood with sand in a large crucible, and exposing them for about an hour to a very intense heat. The charcoal used in various arts and manufactures is commonly prepared on an extensive scale, by the imperfect combustion of wood, built up in large piles, and covered with turf; or else by the distillation of wood in cast-iron cylinders. Lampblack is also chiefly composed of charcoal, consisting of soot, collected from the combustion of the refuse resin, obtained in making turpentine. Ivory-black is another carbonaceous substance, which results from the burning of bones in close vessels. Coke is chiefly composed of charcoal, arising from the distillation of coal, as in the coal-gas manufactories; but it is often contaminated with sulphur and earthy matter.

Carbon, as already stated, appears to exist in the purest form in the diamond. That this splendid gem was an inflammable substance, Sir Isaac Newton sagaciously conjectured, from observing that it was possessed of high refractive power; this idea derived confirmation from the experiments of the Florentine academicians in 1694; and it has been verified more recently by the researches of Guyton Morveau, Smithson Tennant, Sir H. Davy, and other philosophers. The diamond in its natural state is composed of octaedral crystals. It is brittle, but appears to be harder than any other substance; and hence the powder of diamond is used for cutting and polishing the hardest gems, and the diamond itself, for the purposes of ornamental jewellery.

Carbon, as commonly procured by distilling wood, is a good conductor of electricity, though a bad conductor of heat. It remains unchanged by air or water at common temperatures; but when highly heated, readily burns in oxygen gas or common air. It has the property of destroying the smell and taste of many animal and vegetable substances; and it powerfully resists putrefaction, so that tainted meat, if covered with new-burnt charcoal for a few hours, becomes perfectly sweet. The colours of vegetable substances are also greatly affected by charcoal; and hence it is sometimes added to port wine, for the purpose of giving it a tawny hue. Vinegar boiled with it becomes colourless; and it is largely used in refining sugar, in procuring transparent crystals of citric acid, and in other processes. Charcoal obtained by the distillation of animal substances is found most serviceable for these purposes. Freshly-prepared charcoal largely absorbs various gases, a property which appears to depend on the texture of the charcoal; and the different kinds of this substance absorb, in various proportions, aqueous vapour contained in the air.

Carbon unites with oxygen to form three or more compounds, an oxide and various acids. The former of these, *Carbonic Oxide*, is a gaseous body, discovered by Dr. Priestley; and the properties of which were afterwards investigated by Mr. Cruikshank, and by MM. Clement and Desormes, in France. It may be produced from the decomposition of the compounds containing carbonic acid, as by heating in an iron retort a mixture of chalk (carbonate of lime) and charcoal, or of equal weights of chalk and filings of iron or zinc. The gas resulting from either of these operations may be collected in a jar inverted and filled with water; and it must be purified by agitating it with lime-water, to absorb any carbonic acid which may be mixed with it. Carbonic oxide gas is destitute of colour and taste; but it has a disagreeable smell, and is highly injurious to animals, producing giddiness and fainting, if respired when mixed with atmospheric air. It is rather lighter than common air, 100 cubic inches weighing 29.65 grains. It extinguishes flame, but burns with a faint blue light when combined with atmospheric air. When a stream of this gas is burnt under a dry bell-glass, in common air or oxygen gas, no deposition of moisture takes place, as in the combustion of hydrogen and its compounds. If carbonic oxide, with an equal volume of hydrogen, be passed through a red-hot porcelain tube, the tube will become lined with carbon, arising from the decomposition of the oxide, and water will be formed; showing that at a high temperature, oxygen has a greater affinity for hydrogen than for carbon. When carbonic oxide, mixed with half its volume of oxygen, is exposed in a detonating tube to the electric spark, an explosion will take place; and a quantity of carbonic acid will be formed, equal in bulk to the carbonic oxide. Hence it appears that carbonic oxide contains just half as much oxygen as carbonic acid.

Carbonic Acid, or as it was formerly called Fixed Air, is a compound gas, formed both by art and nature, in a variety of processes. An abundant production of this gas takes place in the combustion of animal and vegetable substances in general; but the most interesting example of the formation of carbonic acid occurs when the diamond is intensely heated in common air or oxygen gas. This extremely dense and apparently permanent substance, under these circumstances, becomes wholly converted into carbonic acid; a result which plainly demonstrates it to consist of carbon alone. The combustion of the diamond, with a view to ascertain with accuracy the products of the operation, appears to have been first undertaken by Lavoisier in 1772. In 1797, Mr. Tennant determined from experiment that equal quantities of carbonic acid were obtained when equal weights of diamond or of the purest charcoal were deflagrated with red-hot nitre; and more direct experiments were subsequently made, by causing the diamond to undergo combustion in oxygen gas. This last process may be conveniently executed by means of the apparatus exhibited in the



nexed diagram. It consists of a glass globe, containing about 140 cubic inches, having fitted to its neck a copper cap, with a large aperture, into which a stop-cock is screwed, and from which a jet-pipe, A, rises into the interior of the globe. Just above this jet two wires, CC, terminate, at a short distance apart, one of them being attached to the side of the jet, and the other passing through an insulating glass tube, to the outside of the apparatus, forming the ring D. On the end of the jet is fixed by a socket a small capsule, B, made of platina foil, and pierced with holes like a sieve. It is placed about three-quarters of an inch from the extremity of the jet, and the arm that supports is bent so that the stream of hydrogen, used to set the diamond on fire, shall not play against it. The lower part of the stop-cock screws on a small pillar, fixed to a stand; and at the side is an aperture, from which passes a tube with another stop-cock, by which a bladder filled with hydrogen gas may be connected with the apparatus. When a diamond is to be submitted to combustion, it is to be placed in the capsule B, and the globe must be removed from the pillar and placed on an air-pump, and when exhausted, refilled with oxygen gas. It is then to be carefully screwed on the pillar again, and the bladder of hydrogen gas attached to the lateral tube. The ring D must then be connected with the conductor of an electrical machine, by a chain or wire, and a continued discharge of electric sparks being made to pass between the wires CC, the stop-cock next the bladder must be opened, and a current of hydrogen thrown in, which inflaming, heats the capsule and diamond to white heat, and the diamond taking fire, will burn without any further supply of hydrogen. One or more small diamonds may thus be exposed to combustion, and they will continue to burn, producing a strong white heat, till so reduced in size as to be cooled too low by the platina capsule. When hydrogen is thus employed to inflame the diamonds a little water will be formed in addition to the products of the combustion of the gem. This inconvenience may be avoided by using the flame of carbonic oxide. As, however, no hydrogen has been found to exist in the diamond, it is better to use that gas as the heating agent; for then the carbonic acid produced by the diamonds will be unmixed with any from another source, and it may be collected and its quantity exactly ascertained.*

Carbonic acid, when wanted for the purpose of experiment, may however be most readily obtained by decomposing the combinations of this acid with alkalies or earths. Thus chalk or marble (carbonate of lime), when dropped in small fragments into diluted sulphuric or muriatic acid, will give out abundance of this gas. Vinegar or almost any other acid may be used instead of those just mentioned; as the affinity of carbonic acid for salifiable bases appears to be weaker than that of most if not all other acids. Carbonic acid gas may be collected over water, which however absorbs a large portion of it, even at common pressures and temperatures. The gas is destitute of colour or smell; but, like other acids, it has a sour taste. It is much heavier than common air, and is uninflammable, extinguishing burning bodies which are plunged into it. Owing to its great specific gravity, it may be poured from one vessel to another, like a liquid; and will remain for some time at the bottom of an open jar, without mixing with the atmospheric air above it. Hence a curious effect may be produced, by placing a lighted taper at the bottom of a tall glass jar, and pouring carbonic acid into it, which will immediately extinguish the taper, just as if water had been poured over it. It is highly deleterious to animals, and cannot be breathed without the utmost danger, as appears from numerous instances which have occurred of persons who have lost their lives, by being shut up in a close chamber with braziers or chafing-dishes of burning charcoal, or by descending into vats at the bottom of which this gas had been produced from the fermentation of vinous liquors. It is also sometimes found in the lower parts of wells or mines, where it occasions fatal accidents; and it is called by miners the choke-damp. It is discharged from the surface of the water of some natural springs; from caverns, and narrow, deep valleys, of which phenomena an account will be found in another part of this volume. As water readily takes up this gas, so it may be made by pressure to absorb a large quantity of it. Thus is prepared the liquor called soda water, which in general consists of water only, abundantly impregnated with carbonic acid by pressure and agitation. A similar fluid is formed by nature in the bowels of the earth, constituting peculiar mineral waters, as those of Spa, Seltzer, and Pyrmont; though these waters appear also to contain small quantities of saline matter as well as carbonic acid. Water impregnated with this acid reddens paper stained with a blue colour by litmus; but the tint thus given is not permanent, like that occasioned by the stronger acids. Carbonic acid has been reduced from the state of gas to that of liquid by compression. Mr. Faraday obtained it in this form by disengaging it from carbonate of ammonia by means of sulphuric acid, in a glass tube hermetically sealed, one end of which was immersed in a freezing mixture. The liquid acid was colourless, and floated upon the sulphuric acid and water contained in the tube. It distilled rapidly over, at a temperature below the freezing-point of water. The pressure under which this fluid was formed was estimated to be equal to thirty-six atmospheres. Carbonic acid may be decomposed by the action of the metal potassium, which having a stronger attraction for oxygen than the carbon has, when it is heated in carbonic acid it burns with great splendour; charcoal is deposited, and an oxide of potassium is formed. When carbonic acid obtained by burning a diamond is thus decomposed, the carbon produced is found to be exactly equal in weight to that of the diamond consumed. Carbonic acid may also be decomposed by hydrogen and other bodies; but phosphorus when heated in this gas does not effect its decomposition, the affinity of carbon for oxygen being apparently greater than that of phosphorus.

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* Journal of Science, ed. at R. I., vol. ix. pp. 264, 265.

Besides the two compounds of carbon and oxygen which have been just noticed, there are two if not three more bodies of an acid nature which also appear to be constituted of the same elements, but in different proportions. These are the oxalic, mellitic, and croconic acids.

Oxalic Acid is a production of nature, being contained in the state of a salt, combined with potash, in wood-sorrel (*Oxalis acetosella*), common sorrel (*Rumex acetosa*), and in several species of lichens. It may likewise be procured artificially, by the action of nitric acid on sugar. Bergmann ascertained it to be a peculiar kind of acid, and it was long supposed to be, like most of those derived from vegetables, a compound of carbon and hydrogen with oxygen; but Dobereiner conjectured it to consist of carbon and oxygen only, as is now generally admitted. When obtained from the oxygenation of sugar, or from the decomposition of any of its salts, it forms tetraedral prismatic crystals, resembling in their general appearance, sulphate of magnesia (Epsom salt); and as it is a powerful poison, many fatal accidents have been occasioned by its being mistaken for that salt. In the crystalline state, the oxalic is a hydrated acid, containing a definite portion of water, which cannot be separated from it, without causing its decomposition.

Mellitic Acid is of mineral origin, being found in combination with alumine in the mellite or honey-stone.

Croconic Acid, which was discovered a few years ago by M. Gmelin, is an artificial product, the nature of which has not been properly ascertained; but it appears to be a compound analogous with the two preceding acids, but differing from them in the relative proportions of its constituents.

The following are the respective quantities of carbon and oxygen in the several compounds of those bodies, according to Mitscherlich:

Carbonic Acid = 100 Carbon + 265.23 Oxygen.
Oxalic Acid = 100 Carbon + 198.92 Oxygen.
Carbonic Oxide = 100 Carbon + 132.615 Oxygen.
Mellitic Acid = 100 Carbon + 99.46 Oxygen.[*]

With chlorine carbon unites in three proportions. The *Protochloride of Carbon* may be obtained by passing the vapour of the perchloride through a red-hot tube containing fragments of rock crystal, to increase the heated surface, and thus a portion of chlorine is driven off, and the protochloride is formed. It is a limpid, colourless liquid, which does not become congealed at zero of Fahrenheit, and is volatilized at about 165°. Its specific gravity is 1.55. It is insoluble in water, but mixes readily with alcohol, ether, and oils. It dissolves chlorine, iodine, sulphur, and phosphorus. It is not combustible unless held in the flame of a lamp, to which it communicates a yellow tinge, and gives off much smoke, mixed with fumes of muriatic acid.

Perchloride of Carbon may be formed by exposing carburetted hydrogen gas, mixed with a great excess of chlorine, to the action of light. The perchloride thus obtained is a transparent colourless crystalline substance, having no taste, but an odour resembling that of camphor. Its specific gravity is about 2; it is a non-conductor of electricity, and powerfully refracts light. It is volatile at low temperatures, dissolves at 320°, and boils at 360° Fahrenheit, and it may be distilled without becoming decomposed, its vapour again condensing into crystals as it cools. It is not readily combustible, but burns with a red flame, when held in the flame of a spirit-lamp, becoming decomposed, and forming charcoal (which flies off in smoke) and muriatic acid. It does not dissolve in water, but readily in alcohol and ether, and also in volatile and fixed oils. Potassium burns brilliantly in its vapour, chloride of potassium being formed, and carbon deposited.

There is a third compound called the *Subchloride of Carbon*, which was discovered to have been accidentally formed, in very small quantities, in a manufactory of nitric acid, from nitre and oil of vitriol, in Sweden. It is a solid crystalline body, volatilizing by heat, without decomposition. It has a peculiar smell, but in most of its properties resembles the perchloride, containing however, apparently, a smaller quantity of chlorine than even the protochloride.

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[*] Introd. to Chemistry, vol. i. p. 412.

Iodide of Carbon may be obtained by mixing a saturated solution of iodine in alcohol, with a strong alcoholic solution of potash, when part of the iodine will unite with the potassium, and the oxygen thus disengaged will combine with the hydrogen of the alcohol, to form water; while another part of the iodine combines with the carbon of the alcohol. Iodide of carbon is a lemon-coloured solid, forming bright crystals, having a sweetish taste, and an odour like saffron. Its specific gravity is nearly 2. It does not dissolve in water, but readily in alcohol, and still more so in ether. It also dissolves in oils, and when its solution in oil of lemon is exposed to light, the iodine becomes decomposed, and carbon and iodine are deposited. The strong acids do not act on it, nor the aqueous solution of chlorine, but chlorine gas decomposes it. It evaporates at low temperatures, and dissolves at about 248°, soon becoming decomposed, and giving out vapours of iodine, and a bright charcoal. When this solid iodide is mixed and distilled with perchloride of mercury, a liquid is procured, which is likewise an iodide of carbon, which appears to consist of one proportion of iodine, and one of carbon; while the solid compound contains three proportions of iodine, and two of carbon, the latter, therefore, is a sesqui-iodide, and the liquid an iodide, or rather a protiodide of carbon.

Carbon unites with hydrogen in several proportions, forming a variety of compounds. *Subcarburet of Hydrogen* is formed at the bottom of pools of stagnant water, containing vegetable matter in a state of decomposition. It is a gaseous body, and may be collected in an inverted bottle, with a funnel adapted to it, and the gas thus obtained must be purified by passing it through lime-water, or a solution of potash. It is then colourless and transparent, having but little smell, and being soluble only in a minute proportion in water. It is inflammable, burning with a yellow flame, and giving out much more light than hydrogen. If mixed in certain proportions with atmospheric air or oxygen gas, a violent explosion takes place on the introduction of flame. The spontaneous production of this gas frequently takes place in coal-mines, forming what the miners call fire-damp, which from its tendency to explode, when mixed with common air, has been the cause of numerous dreadful disasters. As the mixture of these gases is exploded only when it comes it contact with flame, various methods have been adopted to furnish the labourers, who work in coal-mines, with light, without incurring the risk of explosion. With this view was invented a kind of mill, for producing continuous circles of sparks, by the action of flint on steel, but the light thus given out is too inconsiderable to be of much service; and hence different kinds of safety-lamps have been contrived, of which the most efficient appears to be that of Sir H. Davy, described in the former volume of this work.*

Carburet of Hydrogen may be procured by heating gently, over a lamp, in a retort, four parts of sulphuric acid, and one of alcohol. In this operation the mixture becomes black, and an abundant disengagement of gas takes place, which may be collected over water, and purified by agitating it with lime-water, or solution of potash. This gas is colourless, and when pure has but little smell. It is inflammable, burning with a dense white flame, which gives much light. Water absorbs about $\frac{1}{8}$ of its bulk of this gas, and it is also absorbed by sulphuric acid, without undergoing decomposition. If, however, these bodies be placed in contact for several days, one volume of sulphuric acid will absorb between eighty and ninety of the gas, forming a peculiar compound. When sulphur is heated in a given quantity of this gas, carbon is separated, and twice its bulk of sulphuretted hydrogen formed. As hydrogen undergoes no change of volume in combining with sulphur, it appears that carburetted hydrogen must contain two volumes of hydrogen condensed into the space of one; hence this gas requires for its complete combustion three volumes of oxygen, and the product will be water and two volumes of carbonic acid. This gas may also be decomposed by passing it, and repassing it, through a red-hot tube of iron or earthenware, when the carbon it contains is deposited, and its hydrogen becomes expanded to double the original bulk. This gas when first discovered, in 1796, was termed Olefiant Gas, from its property of forming a substance like oil when added to chlorine. If equal quantities of carburet of hydrogen and chlorine be mixed together, a diminution of bulk takes place, and a substance is produced, having the appearance of oil, but resembling ether in its general properties. It is a liquid which boils at 152° Fahrenheit, and its specific gravity at 45° is 1.22. It consists of equal volumes of chlorine and carburet of hydrogen, and it has been termed *Hydrochloride of Carbon.*

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* See Pyronomics, p. 335, 2d edit. p. 342.

Olefiant gas also combines with iodine and bromine, to form definite compounds.

In addition to the gaseous carburet and subcarburet of hydrogen, Dr. Dalton and some other writers, mention a third compound of carbon and hydrogen, called super-olefiant gas, as it requires, for its complete combustion, a larger proportion of oxygen than the olefiant gas. But it seems uncertain whether this elastic fluid is a definite chemical compound, or merely a mixture of the preceding inflammable gases. There are, however, several other combinations of carbon and hydrogen, which are, under common temperatures and pressures, liquids or solids. Among the former may be mentioned two liquids obtained by Mr. Faraday, from the fluid matter which occurs in the distillation of whale-oil, for the production of oil-gas, one of which is the lightest of all known bodies, except gases, its specific gravity being 0.602; naphtha, a volatile, inflammable liquid, obtained during the distillation of coal-tar, and also occurring in some parts of the world, in springs, more or less mixed with water; oil of wine, formed during the preparation of sulphuric ether; rectified oil of turpentine, which appears to be very similar in its constitution to naphtha; oil of lemon, and probably other essential oils. The solid compounds of carbon and hydrogen include naphthaline, a crystalline body, which occurs in the distillation of coal-tar; paraffin, another crystallizable substance, found among the products of the destructive distillation of wood; a kind of scaly crystals held in solution by oil of roses, from which they may be separated by exposure to a low temperature, and the crystals may be freed from the adhering oil by pressure between leaves of blotting-paper, kept very cool; and caoutchouc, or the substance called Indian rubber.

There is a circumstance highly deserving of attention with regard to the compounds of carbon and hydrogen which may here be noticed. So far as we are acquainted with the atomic constitution of these bodies, they appear to be susceptible of arrangement in classes or sections, each division consisting of a given number of carburets of hydrogen, agreeing with each other in the relative proportions of their constituents, but differing more or less in their properties and modes of action. As examples of the compounds in question may be specified olefiant gas, paraffin, Faraday's volatile liquid carbo-hydrogen, and oil of wine, in all which carbon and hydrogen exist in equal proportions; and oil of lemon, oil of turpentine, and a liquid called camphogene, or the basis of camphor, in which the quantity of carbon is to that of hydrogen, as 5 to 4. Other instances of a corresponding nature will be noticed in treating of phosphorus.

Carbon unites with nitrogen to form a remarkable compound called *Cyanogen*, or the basis of prussic or hydrocyanic acid, which, by its combination with oxide of iron produces Prussian blue. It is properly a bicarburet of nitrogen, and in order to obtain it, it is necessary first to form the salt, formerly called prussiate of mercury, but now cyanuret of mercury. This is composed by boiling red oxide of mercury, with twice its weight of Prussian blue, in a sufficient quantity of water, when those bodies will unite to form a crystallizable compound. The cyanuret of mercury, thus obtained, after having been carefully dried, at a temperature below 212° Fahrenheit, must be heated in a small glass tube, when it becomes black, and liquefies, and is at length decomposed. The mercury becoming condensed in the cold part of the tube, and a gas being at the same time evolved, which must be collected over mercury. This is cyanogen, which at the usual temperature and pressure of the atmosphere, is a permanently elastic fluid, though, as elsewhere stated, it has been condensed to the liquid state by Mr. Faraday. It has a peculiar pungent odour, resembling that of bitter almonds, and it is destitute of colour. It is inflammable, burning in contact with air, with a fine purple flame; but any burning body, as a lighted match, plunged into it becomes extinguished. It dissolves in water and more largely in alcohol. The aqueous solution reddens vegetable blues, and according to Vauquelin, it becomes spontaneously decomposed, and converted into carbonic and hydrocyanic acids, ammonia, a peculiar acid called the cyanic, and a brown substance containing carbon; the ammonia combines with the acids, and the carbonaceous compound is deposited. These phenomena are owing to the reaction of the elements of cyanogen upon those of water. When cyanogen is mixed with oxygen, it may be exploded by the electric spark. If one volume of this gas, and two of oxygen be detonated over mercury, the product will consist of two volumes of carbonic acid, and one of nitrogen.

Cyanogen, though a compound, enters into combination with elementary bodies, in a manner very similar to the mode of action of oxygen and chlorine. Thus, like oxygen, it combines with several of the metals, constituting compounds, which might be termed cyanides, though they are generally called cyanurets, and as chlorine forms with hydrogen muriatic acid, so cyanogen combined with hydrogen forms *Hydrocyanic* or *Prussic Acid.*

The chemical properties of this acid may here be described. It may be obtained by heating, in a tubulated glass retort, three parts of cyanuret of mercury, with two parts by weight of concentrated muriatic acid. A vapour rises, consisting of water, and the muriatic and prussic acids, the former of which may be separated by passing the vapour through a narrow tube, containing fragments of marble. It must then be passed over dry chloride of calcium, and condensed in a vessel surrounded with ice. The prussic acid thus obtained, is a limpid fluid with a strong smell, like that of laurel water, or bitter almonds, and an acrid taste. It is extremely deleterious, proving destructive to animal life, in a small quantity, when either swallowed or inhaled, and therefore the utmost care should be taken in preparing it to avoid breathing the vapour, which, when much diluted with atmospheric air, will cause giddiness and headache. This acid volatilizes so rapidly, as to freeze in consequence of the cold produced by its evaporation. Its specific gravity compared with hydrogen is 13.5, 100 cubic inches weighing 28.593 grains. It consists of one volume of cyanogen, and one of hydrogen. This acid slightly reddens litmus paper, and it combines with alkalies, and other bases, to form salts; but its affinities are so feeble, that these compounds are decomposed even by carbonic acid. It dissolves in any proportion in water and alcohol; and it is occasionally used as a powerful medicine, and therefore in small doses, chiefly as a sedative, in cases of phthisis pulmonalis.

Boron.

This substance is usually obtained by heating together, in a copper or iron tube, one part of boracic acid, formerly called the sedative salt of Homberg, previously melted and powdered, and two parts of potassium; when the temperature being raised till the tube becomes red, the metal attracts the oxygen from the acid, and the boron may thus be procured, in the form of a brown powder, having neither taste nor smell, and insoluble in water, alcohol, ether, or oil, even when heated. It is permanent in the air at common temperatures, and is infusible. It is a non-conductor of electricity; and its specific gravity is more than twice that of water. It does not decompose water when heated to 176° of Fahrenheit. At low temperatures, boron remains unchanged in atmospheric air or oxygen; but at a temperature of 600° of Fuhrenheit it burns with brilliancy, becoming united with oxygen, and forming *Boracic Acid.*

This acid, which is used in medicine, is generally obtained from the decomposition of borax by sulphuric acid. It may be crystallized in the form of small, shining plates or scales, in which state it is combined with water, constituting a hydrate; but by exposure to a strong red heat, it melts into a hard transparent glass; and at a white heat it becomes slowly sublimed. In the state of hydrate its specific gravity is 1.48, and in that of glass about 1.8. It dissolves sparingly in water, and the solution reddens vegetable blues, like other acids; but when applied to paper wetted with infusion of turmeric, it acts like an alkali, tinging it brown. The solution of boracic acid in alcohol burns with a green flame. This acid is found naturally in the hot springs of Sasso, in Tuscany, and also in the Lipari Islands; and it likewise occurs combined with magnesia in the mineral called boracite.

Boron may be made to combine with chlorine, by passing that gas over charcoal and boracic acid in a state of incandescence. The *Chloride of Boron* thus formed is a gas, which may be collected over mercury. It is colourless, heavier than air, and emits fumes when exposed to air; but does not undergo decomposition when strongly heated.

A gaseous acid called the *Borofluoric Acid*, was obtained by the French chemists, Gay Lussac and Thenard, by heating together vitrified boracic acid and fluor spar (fluoride of calcium). In this process the oxygen of the boracic acid appears to enter into union with the calcium of the spar, forming oxide of calcium, and the fluorine being thus set free, unites with the boron to form the acid gas. It is colourless, but has a powerful smell, like muriatic acid; is highly deleterious when respired, and extinguishes flame. It has an acid taste, and strongly reddens vegetable blues. It instantly carbonizes animal and vegetable subtances, but it has no effect upon glass; thus exhibiting a striking dissimilarity with the hydrofluoric acid. When mixed with oxygen gas it is not decomposed, but it powerfully attracts moisture; and hence when bubbles of it are allowed to escape into the air, a dense white cloud is produced, arising from the combination of the borofluoric acid with the hygrometric water of the atmosphere.

Silicon.

This is a peculiar solid body, hitherto undecomposed, and therefore considered as elementary, which in the state of combination with oxygen is one of the most abundant substances in nature. Sir H. Davy appears to have effected the decomposition of the oxide, or rather acid of silicon (siliceous earth), by means of Galvanism; but he was unable to collect the product of the operation so as to ascertain its properties. Berzelius separated the silicon from its acid by means of iron, and his experiments were repeated by Professor Stromeyer; and the former at length succeeded in procuring silicon in an uncombined state. The process which he recommends is not difficult, and its efficacy depends on the affinity of potassium for oxygen, which it attracts when the double fluate of silica and potassa is heated nearly to a red heat in a glass tube closed at one end; fragments of potassium being then introduced into the tube and made to mix with the fused salt, heat is again applied, and a feeble detonation ensues. The mass must then be left to cool, and the product being thrown into cold water, hydrogen is disengaged from the action of the siliciuret of potassium, which becomes converted into hydruret of silicon and potassa. The hydruret thus obtained being heated in a platina crucible, the hydrogen will be driven off, and the silicon will remain, in the form of a snuff-coloured or nut-brown powder. It does not burn either in air or oxygen gas; neither is it fused or at all changed by exposure to powerful heat.

Silicic Acid.—Silicon, though thus incombustible, may be indirectly united with oxygen by various methods, forming, as already observed, the body known as siliceous earth. The combination may be effected by mixing silicon with dry carbonate of potassa, and exposing it to red heat, when the oxygen of the carbonic acid will unite with the silicon, and a combination of silicic acid and potassa will be formed. If fused nitrate of potassa be used instead of the carbonate, no effect will take place; though the addition of a little dry carbonate of potassa occasions immediate deflagration. This peculiar phenomenon is owing to the influence of the alkali, which having a strong affinity for silica, disposes the silicon to combine with the oxygen of the carbonic acid, in which the union between carbon and oxygen is but weak. Nitric acid, on the contrary, being a very strong acid, entirely prevents the alkali of the nitrate from acting on the silicon; unless the substances be heated to whiteness, and then the nitric acid becoming decomposed, the silicon will attract its oxygen, and rapid combustion will take place. When silicon is heated with caustic potassa or soda, it burns in the oxygen of the water which they contain, forming silica. This substance may be found nearly pure in colourless rock crystal or quartz; and in flint the earth is only combined with a little iron. In order to obtain silica in a state of absolute purity, rock crystal may be reduced to powder by heating it red-hot, and throwing it into water, and then bruising it in a mortar: one part of this powder is to be fused in a silver crucible, with three times its weight of potassa, and the mass thus formed being dissolved in water, muriatic acid is to be dropped into the solution so long as any precipitate is produced; the liquid is then to be poured off, and the precipitate, which is acid of silicon, must be repeatedly washed with distilled water, and then dried. Silica thus obtained is a white, tasteless powder, feeling harsh when rubbed between the fingers. It is nearly insoluble in water, and probably in all acids, except the hydrofluoric. It is infusible alone before the blowpipe, unless the flame be fed with oxygen gas, when it melts with difficulty into a colourless globule. Though water has no action on it after it has been dried, yet, according to Kirwan, when first precipitated and still moist, it dissolves in a thousand parts of distilled water; and it is certain that nature has some process for the solution of this substance, since it is found, though in minute proportions, in the water of some hot springs, as the Geysers, in Iceland. When first prepared and minutely divided, it readily dissolves in solutions of potassa or soda; but ammonia has no effect on it. When silica is fused with a large portion of potassa, a compound is produced readily soluble in water, forming the *liquor silicum*, liquor of fliata, of old writers. Professor Seigling, of Erfurdt, having prepared this liquor with a large quantity of water and of alkali, he suffered it to stand for eight years in a glass vessel, covered with paper, when crystals of salts of potash were formed at the bottom of the vessel, and the remaining liquid, about two ounces, was covered by a transparent crust, consisting partly of carbonate of potash, and partly of crystallized silica; the latter so hard as to strike fire with a steel. When silica is fused with a small proportion of potash or soda, without water, the product is that useful substance glass. In the manufacture of glass a variety of other substances are occasionally added to the silica and alkali, for various purposes: among these may be mentioned black oxide of manganese, which renders glass colourless, and improves its transparency; litharge or oxide of lead, used in making what is called flint glass; lime, which is added to the ingredients for crown or the best window glass; and boracic acid or borax, employed in making artificial gems. White arsenic, nitre, brick clay, and other substances are sometimes added to improve the quality of glass; or in the coarser kinds, to increase the quantity. Silica was long classed among the earths, from which it differs decidedly, in not forming salts with acids; the hydrofluoric acid, as already observed, being the only one with which it enters into combination. Hence it appears that silica cannot act the part of a base like the alkalies, earths, and metallic oxides. With several of these, however, it is found combined in various minerals, and therefore as to its mode of action it has an obvious analogy with acids, and some chemists have given it the name of silicic acid, instead of silicic oxide: and to the compounds formed by its union with several earths and metallic oxides, they have applied the designation of silicates; and thus glass might be considered as a silicate of potassa or soda.

Among the combinations of silicon with the elementary substances, may be mentioned those that it forms with chlorine and with fluorine. When silicon is heated in chlorine, as when a current of that gas is made to pass over red-hot silicon in a porcelain tube, a fuming liquid is obtained of a yellow colour, extremely volatile and irritating, which when exposed to moisture becomes decomposed, forming muriatic acid and silica. This is the *Chloride of Silicon*. When potassium is heated in the vapour of this chloride, it burns, with the production of siliciuret and chloride of potassium.

Silicofluoric Acid, or *Fluoride of Silicon,* may be made by distilling in a retort three parts of fluor spar and two of powdered silica, with an equal weight of sulphuric acid, when a gas will be produced which may be collected over mercury. Water must be carefully excluded in this operation, therefore the apparatus must be made quite dry. Silicofluoric acid is a colourless gas, having a pungent smell, much like that of muriatic acid, and a very sour taste. It is more than 3½ times the weight of common air. It extinguishes the flame of a taper, and forms white fumes when exposed to moisture, being readily absorbed by water; from which, however, silica is precipitated, hydrofluoric acid being produced. If the beak of a retort from which this gas is issuing be plunged beneath water, it soon becomes choked by the abundant deposition of hydrated silica, which sometimes forms tubes through the water, by which the gas passes off into the air.

Silicon likewise unites with sulphur, and with several of the metals, especially platina and iron.

Phosphorus.

This body being highly inflammable, and consequently having a strong affinity for oxygen, seldom occurs naturally except in combination with that element, constituting phosphoric acid united with some base, in the state of a salt. It is thus found in the bones of animals, the denser parts of which consist principally of phosphate of lime, or the combination of lime with phosphoric acid, and from the decomposition of this earthy salt phosphorus is procured. The usual process is to digest a quantity of calcined or burnt bones, reduced to powder, in half their weight of strong sulphuric acid. The phosphate of lime is thus decomposed, and the phosphoric acid, after being separated from the lime, undergoes a further decomposition by being mixed with powdered charcoal, and strongly heated in an earthen retort, when the charcoal will combine with the oxygen of the acid, and the phosphorus passing over, may be received in a vessel of water, under the surface of which the beak of the retort must be plunged. The process is troublesome, and requires much attention on the part of the operator.

Phosphorus thus obtained is a flesh-coloured, slightly-transparent solid, nearly the consistence of wax; which, on account of its inflammability, must be preserved under water. If heated in water, it melts at about 110° Fahrenheit, and boils or becomes evaporated at 550°. When exposed to the atmosphere at common temperatures, it emits a light smoke, and a peculiar odour, resembling that of garlic, giving out in the dark a beautiful pale-green light. In this case it undergoes a slow combustion. It is soluble in essential oils, and communicates to them the property of shining in the dark. In pure nitrogen gas it is not luminous, undergoing no alteration at any temperature. But it appears that the smallest possible quantity of oxygen will suffice to produce some degree of combustion;* for it will burn, or at least give out light in the exhausted receiver of an air-pump. Phosphorus may be set on fire by friction at a low temperature, and at about 100° it takes fire, and burns with intense brilliancy, throwing off abundance of white fumes.

This substance combines with oxygen in different proportions. *Oxide of Phosphorus* is a white substance with which phosphorus becomes covered when kept for some time under water. It is very inflammable, and may be used in making phosphoric match-boxes. For this purpose a piece of phosphorus must be introduced into a small phial, melted slowly by applying heat externally, and stirred about with a hot iron wire till the inside of the bottle becomes coated with the semi-fluid oxide, which is then to be preserved for use, by closing the bottle with a cork. When a light is wanted, it is only necessary to dip into the bottle a brimstone-match, and on withdrawing it with a small portion of the oxide of phosphorus adhering to its extremity, the sulphur will become inflamed, and the match may be used for lighting a taper or any other purpose.

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* It appears from the experiments of Dr. John Davy and others, that "when oxygen gas is rarefied, phosphorus shines in it; and that when condensed it ceases to shine. With an augmented pressure of a column of mercury of 16 inches, when heated with a spirit-lamp in this gas, it emitted no light till it fused; then it burst into flame and burnt explosively, and the oxygen was condensed in an instant. . . . Compression and rarefaction, in the instance of common air, has an effect analogous to that mentioned when speaking of oxygen. . . . When phosphorus is placed on the plate of an air-pump, under a receiver, and the air exhausted, the brightness of its light in the dark rather increases with the exhaustion; and in the nearly perfect vacuum formed by a good pump, its light was not diminished. When the air has been suddenly readmitted, the light has been extinguished, and for a few seconds it has ceased to shine."—*Observations on Phosphorus.* By J. Davy, M.D., F.R.S., in Jameson's Journal of Science.

There is some uncertainty as to the number of the acid combinations of phosphorus and oxygen. Three may be discriminated as containing different proportions of their constituent elements. These are the hypophosphorous, the phosphorous, and the phosphoric acids. The relative quantities of phosphorus and oxygen in these acids are thus stated by Mitscherlich:

Phosphoric Acid = 100 Phosphorus + 127.450 Oxygen.
Phosphorous Acid = 100 Phosphorus + 76.470 Oxygen.
Hypophosphorous Acid = 100 Phosphorus + 25.490 Oxygen.*

The *Phosphorous Acid* is a white, volatile substance, which may be obtained by burning phosphorus in a tube, with a relatively small portion of air, and at a moderate temperature; it may then be collected in the state of a white powder, which, on exposure to the atmosphere, decomposes the water suspended in it, considerable heat is given out, and it combines with an additional portion of oxygen to constitute phosphoric acid. The phosphorous acid speedily dissolves in water, to which it gives a sour taste, and the solution reddens vegetable blues. With various salifiable bases this acid forms certain salts called phosphites. Both the phosphorous and the phosphoric acids combine in definite proportions with water, forming hydrated acids.

When phosphorus is rapidly inflamed, as in its combustion in oxygen gas, abundance of white vapours are produced, which become condensed into deliquescent flakes, adhering to the interior of the receiver, or falling to the bottom like snow: this substance is the *Phosphoric Acid*. This acid may also be obtained from the decomposition of atmospheric air by phosphorus. Thus if a piece of phosphorus be placed in a watch-glass, upon a plate of glass, and covered with a tall receiver, on setting it on fire with a red-hot iron it will at first burn rapidly, and then more slowly till the oxygen is nearly consumed. The combustion, however, may be renewed by occasionally lifting the receiver slightly, so as to introduce fresh supplies of air from time to time, till the phosphorus is all burnt, and thus will be formed a quantity of anhydrous phosphoric acid, as before, in the form of flakes of snow. This substance dissolves in water with a hissing noise, and the evolution of much heat; and it is also soluble in alcohol. Phosphoric acid may likewise be obtained by heating small fragments of phosphorus in nitric acid. Though phosphoric acid will unite readily with water, on heating the solution the greater part of the water may be driven off, and if the residue be exposed to a low red heat it melts, and on cooling forms a kind of glass, sometimes called glacial phosphoric acid. The solid acid attracts water from the air, it has no smell, but an intensely sour taste, and becomes volatilized without decomposition at a bright red heat. It unites with salifiable bases to produce the salts called phosphates, one of which, the phosphate of soda, is used in medicine; and phosphate of lime, or the combination of this acid with calcareous earth, constitutes a considerable part of the bones of animals, from the decomposition of which, as already stated, phosphorus is usually obtained.

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* Introduction to Chemistry, vol. i. p. 299.

The *Hypophosphorous Acid*, is so named as containing a smaller proportion of oxygen than the phosphorous acid. The salts formed by this acid are all readily soluble, and highly deliquescent when exposed to the air.

The phosphoric acid is capable of undergoing modifications, which materially influence its properties, without causing any alteration of the proportions of its constituents. "If liquid phosphoric acid be evaporated, and heated to such a temperature as may be judged capable of expelling the chief part of the water, it is changed into pyrophosphoric acid: and the same change takes place when the acid exists in a salt combined with an alkali. Although between phosphoric and pyrophosphoric acid there is no known difference of composition, the properties of each are essentially different. Pyrophosphoric acid produces, with oxide of silver, a white salt; phosphoric acid, a yellow one: the former is a less energetic acid, it has less saturating power, and is even separated from its combinations by phosphoric acid."*

This apparent identity of composition occurs in various other compounds, constituting the phenomenon which has been termed Isomerism.* Another instance of it will be found in the combination of phosphorus with hydrogen, in the existence of two oxides and two chlorides of tin, differing in properties, but having the same atomic constitution, in some other combinations of oxygen with metals, and in some of the acids with compound radicals. Among the numerous carburets of hydrogen, cases of a corresponding mode of union have been noticed, giving rise to what is termed Polymerism;* and there is another kind of relation between the combining proportions of bodies expressed by the term Metamerism.* These phenomena have so much similitude, that their origin may with probability be referred to a common cause; but the subject, which is highly interesting, requires further investigation.

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* Donovan's Treatise on Chemistry, in Cabinet Cyclopædia, p. 221. See also Mitscherlich's Introd. to Chem., vol. i. pp. 391—394; and Johnston on Chemistry, in Report of British Association for 1832, pp. 457—460.

Phosphorus combines with chlorine in two proportions. *Protochloride of Phosphorus* may be obtained by distilling phosphorus mixed with corrosive sublimate, or perchloride of mercury, when calomel, or protochloride of mercury will be formed by the decomposition of the sublimate, and the portion of its chlorine which is thus set free, will immediately combine with the phosphorus. Protochloride of phosphorus when first obtained, is a liquid of a reddish colour, holding some phosphorus in solution, which it deposits on standing. It then becomes transparent and colourless. Its specific gravity is 1.45. It has a suffocating smell, and gives off acid fumes when exposed to the air, owing to its absorbing water, which it readily decomposes, the hydrogen of the water combining with chlorine to form muriatic acid, and the oxygen with the phosphorus to form phosphorous acid. Its vapour is combustible; and when in a dry state, it does not affect the colour of vegetable blues.

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* Isomerism is a term derived from the Greek Ἴσος, *equal*, and Μέρος, *a part;* Polymerism from Πολὺς, *many*, and Μέρος; and Metamerism from Μετὰ, *according to*, and Μέρος. The following explanation of these terms is given by Mr. Johnston: "Isomeric bodies are those which contain the same absolute and relative number of atoms of the same elements, and have consequently the same atomic weight. Polymeric are those which contain the same relative but not the same absolute number of atoms of the same elements, and whose atomic weights are consequently unlike. Metameric are those which, while they contain the same absolute and the same relative number of atoms of the same elements, yet constitute substances belonging to an entirely different class of bodies, or a different order of chemical compounds." —*Reports of the British Association* for 1832, pp. 435, 436.

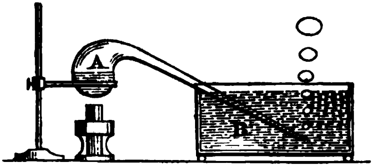
Isomorphism (from the Greek Ἴσος, and Μορφὴ, *figure* or *shape*), correspondence of form between bodies composed of different elements, refers to another class of chemical phenomena, brought to light through the recent researches of men of science. It occurs in crystalline bodies, and will be further noticed in the Treatise on Mineralogy.

Perchloride of Phosphorus.—When phosphorus is introduced into chlorine gas, it takes fire spontaneously, burning with a pale flame, and the product is a white pulverulent substance, which condenses on the sides of the vessel. It is volatile at temperatures under 212°, but if heated under pressure, it fuses and becomes crystallized on cooling. It acts violently on water, double decomposition taking place, and hydrochloric or muriatic acid, and phosphoric acid being produced.

Phosphorus very readily combines with iodine, for when these substances are mixed in an exhausted vessel, great heat is evolved but no light, and the result is a reddish or orange-coloured compound, the *Iodide of Phosphorus*, which powerfully decomposes water. *Periodide of Phosphorus* is a black compound, which may be formed by heating together its constituent parts, and like the preceding it decomposes water.

According to M. Balard, phosphorus combines with bromine in two proportions, but the compounds thus formed have been but slightly examined.

Phosphorus combines with hydrogen to form two compounds. The former of these, called *Phosphuretted Hydrogen*, may be readily procured by heating phosphorus in a solution of caustic potash.



This combination may be formed by means of the apparatus represented in the preceding figure. Let about a quarter of an ounce of phosphorus be introduced into the small retort, A, which is to be filled up to its neck with the solution of caustic potash, and the lower end of the retort is to be dipped under water in the trough, B; then, on heating the retort gradually, with a lamp, gas will be generated, which will rise from the end of the tube, through the water, in bubbles, and these on coming in contact with the air will inflame with a slight explosion. When the atmosphere is still, each bubble as it bursts produces an expanding ring of dense vapour, resulting from the sudden formation of phosphoric acid and water. Some care is necessary in the conduct of this experiment, so as to include as small a portion of air as possible in the retort, since the first bubbles of phosphuretted hydrogen gas that are formed will, as soon as they come in contact with the air in the retort, take fire, and the retort may be broken by the percussion. This gas may also be procured by dropping small pieces of the compound called phosphuret of lime, into muriatic acid, largely diluted with water, and the gas rising as before, will take fire on coming in contact with the air. The same compound may be obtained by heating in close vessels solid hydrated phosphoric acid; and the gas produced by this or either of the preceding operations, may be preserved by suffering it to pass into an inverted jar filled with water, when it will rise to the top, and gradually displace that liquid. Phosphuretted hydrogen is a colourless gas, with a nauseous smell, like onions or assafœtida, and a very bitter taste. It loses its inflammable property by being kept over water, which absorbs about two per cent. of the gas, and thus acquires its characteristic taste and odour. It burns with great splendour in oxygen gas, in chlorine with a beautiful pale blue light, and it also burns in nitrous oxide.

The gas which has been styled *Bihydroguret of Phosphorus*, or hydrophosphoric gas, may be obtained by heating the solid hydrated phosphoric acid, in a small retort, and collecting the product over mercury. It is colourless, and resembles the preceding compound in taste and smell, but is less disagreeable. Though it does not inflame spontaneously in atmospheric air, it explodes when heated to 300°, and more readily when heated in oxygen gas; it also takes fire spontaneously in chlorine. Professor Henry Rose has ascertained that this and the preceding are isomeric bodies; so that there are two kinds of phosphuretted hydrogen, one which inflames spontaneously in atmospheric air, and another which is relatively non-inflammable, both consisting of one volume of phosphorus in vapour, and three volumes of hydrogen gas, condensed to the bulk of two volumes.

The combination of phosphorus with carbon was first effected by M. Proust. *Phosphuret of Carbon* may be obtained from phosphuret of lime, by suffering it to remain in water till it gives out no more gas; a considerable excess of muriatic acid is then to be added to the liquid, and after agitating it a few moments it must be thrown on a filter, and the substance which remains on it is to be washed and dried. It seems from this process that carbon is contained in phosphuret of lime, as usually prepared, and it is also procured in the process for making phosphorus. Phosphuret of carbon is a soft powder, of a dull lemon colour, destitute of taste or smell, which when exposed to air absorbs water, which it decomposes, becoming converted into phosphorous acid. Exposed to a red heat it burns, and gradually gives out its phosphorus, the charcoal remaining behind in the form of a black substance, coated with phosphoric acid, which prevents its complete combustion. When the powdered phosphuret is thrown over the fire in small quantities, it forms beautiful scintillations.

Sulphur.

This substance is well known, as being of common occurrence, and employed in medicine and the arts for a variety of purposes. It is often found in volcanic districts, among the matter discharged from the craters of burning mountains, and in several states of combination it forms a constituent of numerous minerals. Flowers of sulphur and roll sulphur differ only as to their state of aggregation. The latter exhibits a crystalline structure, especially if melted, and suffered to cool slowly. Though sulphur may be considered as an insipid and almost inodorous body, it exhales a peculiar smell when heated or exposed to friction. Heat and friction also render it highly electric, and like sealingwax, it is a non-conductor of electricity. When raised to the temperature of about 180° Fahrenheit, it sublimes, strongly exhibiting its characteristic odour; at about 220° it becomes fused, and if the heat is increased and continued, it forms a viscid semi-solid mass, which, when poured into warm water, assumes the consistency of soft wax, exhibiting a red tint; and in this plastic state, it is used for taking impressions of coins, medals, or sculptured gems, as it becomes quite hard on cooling. Sublimed sulphur (flowers of sulphur), when examined by a microscope, is found to consist of minute crystals.

Sulphur is well known to be highly inflammable, combining with the oxygen of atmospheric air, even at the temperature of 190°; though it then burns but slowly, with a faint blue light; but at 300° its combustion goes on rapidly, with the evolution of much light and heat. In oxygen gas it burns brightly, producing a large lilac-tinted flame. It combines with oxygen in four different proportions, to form definite compounds, all of which are acids, whose relative composition will appear from the following table:

Sulphuric Acid = 100 Sulphur + 149.136 Oxygen.
Hyposulphuric Acid = 100 Sulphur + 124.280 Oxygen.
Sulphurous Acid = 100 Sulphur + 99.420 Oxygen.
Hyposulphurous Acid = 100 Sulphur + 49.710 Oxygen.

Sulphurous Acid.—This is a gaseous compound, which may be obtained by the direct union of its constituents, when sulphur is burnt in atmospheric air perfectly free from moisture, or in oxygen gas. It may also be procured by boiling two parts of mercury in three of sulphuric acid; or by heating together, in a small glass retort, equal parts of powdered black oxide of manganese and flowers of sulphur. In the former of these processes, the mercury partially decomposes the sulphuric acid, becoming oxidated by uniting with a portion of its oxygen, and sulphurous acid gas is thus formed. In the latter case, the sulphur attracts from the metallic peroxide a part of its oxygen, and the gaseous acid is produced as before. It must be collected and preserved over mercury, as water absorbs more than thirty times its volume of this gas. It communicates to water the odour of burning brimstone, and an astringent acid taste. At first the solution bleaches vegetable colours, but after being kept some time, it changes blue colours to red. The gas equally effaces colours, and it is therefore used in bleaching silk, cotton, straw, and other substances. It has likewise the property of checking vinous fermentation, and it is hence occasionally employed in the processes of brewing and making wines. This gas is not inflammable, extinguishing burning bodies which are plunged into it; hence when the soot is on fire in a foul chimney, if it be filled with the fumes of sulphurous acid, by heating sulphur below on an iron plate, the fire will be put out, as the soot cannot burn in an atmosphere of this gas. It is speedily destructive to animals confined in it. Sulphurous acid may be condensed to the liquid state, by exposure to pressure equal to the weight of two atmospheres, at the temperature of 45°, and by means of intense cold, independent of pressure. In this form its specific gravity has been estimated at 1.45, and it boils at 14°, inducing the speedy congelation of liquids in contact with it by its rapid evaporation.

Sulphuric Acid.—The quantity of oxygen contained in this acid is just half as much again as that in the preceding compound, and therefore sulphuric acid may be produced by combining sulphurous acid with an additional portion of oxygen. The acid gas will not unite with oxygen when simply mixed with it, without the intervention of some other body; but if water be present the combination may be effected. Thus when oxygen gas is inclosed in an inverted jar over an aqueous solution of sulphurous acid, the oxygen will be slowly absorbed, and sulphuric acid may be thus obtained, largely diluted with water, a considerable portion of which may be expelled by evaporation. This acid is used for numerous purposes, and is therefore manufactured on an extensive scale, the process generally adopted in this country being founded on the same principle with that just described. It consists essentially in burning a mixture of about eight parts of sulphur and one of nitre (nitrate of potash), in a close chamber lined with lead, and containing water. Here sulphurous acid is first formed from the combustion of the sulphur, and the partial decomposition of the nitrate of potash furnishes the additional quantity of oxygen, to form sulphuric acid, when the products of the combustion come in contact with the water. The acid thus procured is afterwards concentrated by boiling, and purified by distillation. Another method of obtaining this acid is from the decomposition of sulphate of iron, or the compound of sulphuric acid and oxide of iron, when distilled from earthen retorts in a reverberatory furnace. The salt used in this operation being called green vitriol, or martial vitriol, the acid which it produced received the name of oil of vitriol, with reference to its consistence and general appearance. This acid emits whitish or gray vapours when exposed to the air, and if it be distilled with a gentle heat, and the receiver kept cool with snow or pounded ice, a transparent colourless vapour will pass over, and become condensed into a crystalline solid, resembling fibres of asbestos, which is the pure acid. The anhydrous acid, thus prepared, is so extremely volatile, that it rises in fumes at a low temperature, and greedily attracts moisture from the air. Liquid sulphuric acid consists of 81.63 parts by weight of the pure or anhydrous acid, and 18.37 of water. It then forms the oily fluid already described, which has the specific gravity of 1.85, which boils at 600°, and freezes at 15°, undergoing in the solid state a considerable amount of contraction. It readily absorbs moisture from the air, whence its application in many processes for the purpose of obtaining gases free from aqueous vapour. When mingled with a moderate quantity of water, it produces a high degree of heat. The concentrated acid acts as a caustic when applied to the skin, and it blackens and corrodes both animal and vegetable substances. According to Dr. Ure, the solid or anhydrous sulphuric acid, if dropped on paper, will burn holes in it as readily as a red-hot iron, and when dropped into water it hisses as if a red-hot coal had been thrown into it: at the temperature of 64° it dissolves into a thin liquid.

Hyposulphurous Acid may be formed by digesting filings of iron in water impregnated with sulphurous acid gas, which is partially decomposed, forming oxygen and hyposulphurous acid; the oxygen combines with the metal to form oxide of iron, which unites with the acid, and the result is the salt called hyposulphite of iron, remaining in solution in the water. Various compounds of this acid with bases may be obtained by other processes; but it seems questionable whether it can be procured in an uncombined state. Dr. Thomson announced the production of an acid of sulphur containing a larger proportion of oxygen than the preceding, but less than any of the others (its combining quantity of oxygen being a mean between the hyposulphurous and the sulphurous acids), to which he gave the appellation of Subsulphurous Acid. But from an analysis of hyposulphite of barytes, and other experiments of Professor Rose, it appears that this acid consists of the same constituents as the hyposulphurous, and in the same proportions, but each atom contains double the number of atoms of sulphur and of oxygen. It is, therefore, an example of a polymeric compound.

Hyposulphuric Acid.—When sulphurous acid gas is passed through water in which the powder of black oxide of manganese is kept suspended by agitation, the metallic oxide becomes partly decomposed, and the oxygen which it gives out combines with the sulphurous acid in two proportions, forming sulphuric and hyposulphuric acid. Both these acids will unite with the oxide of manganese, and to obtain the hyposulphuric separate, solution of barytes must be added, which will decompose the metallic salts, forming a soluble hyposulphate, while the other ingredients will be precipitated. The hyposulphate of barytes is then to be decomposed by means of sulphuric acid, and the hyposulphuric acid thus obtained may be concentrated by placing it under the exhausted receiver of an air-pump, with sulphuric acid. The acid which may thus be raised to the specific gravity of 1.347, is an inodorous liquid which reddens litmus paper. It forms soluble salts not only with barytes, but likewise with lime, strontia, and protoxide of lead; thus essentially differing from the sulphuric acid.

Sulphur does not apparently combine with nitrogen, but with hydrogen it forms two compounds, both which, like acids, unite with the alkaline and other bases to form a kind of salts. That which contains the smaller proportion of sulphur, has been called *Sulphuretted Hydrogen*, and sometimes *Hydrosulphuric*, or *Hydrothionic*[*] *Acid*. It may be formed indirectly by pouring sulphuric acid, diluted, on combinations of iron or other metals with sulphur. It is a colourless transparent gas, readily absorbed by water, and has a very offensive smell, similar to that observable in putrid eggs, or in the washings of a foul gun-barrel; the peculiar odour in these and other cases of its occurrence, depending on the presence of this gas. Hydrosulphuric acid appears to be composed of 100 parts by weight of sulphur, and 6.184 of hydrogen. It reddens litmus paper, and combines with many of the salifiable bases, forming a class of salts called hydrosulphates, which are decomposed by all the oxygen acids except the carbonic.

Hydrosulphuric acid gas is inflammable, burning when mixed with common air or oxygen, but it extinguishes other burning bodies immersed in it. It tarnishes quicksilver, gold, and mercury, and blackens white oxide of lead (ceruse), or that of bismuth. It is highly noxious to animal life when respired, and it has been said that a horse has been known to perish in air containing only $\frac{1}{250}$ part of this gas. It is, however, sometimes employed medicinally, when largely combined with water, being used in this state for bathing, and taken internally. The mineral springs of Harrowgate, Knaresborough, and others, derive their sensible qualities from the hydrosulphuric gas with which they are impregnated.

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[*] From the Greek Ὕδωρ, *water*, and Θεῖον, *sulphur*.

Bisulphuret of Hydrogen, or *Super-sulphuretted Hydrogen*, called also *Hydrosulphurous Acid*, is a compound containing a larger portion of sulphur than the former. It is a yellow, oily liquid, heavier than water, greatly resembling in its smell and taste the solution of sulphuretted hydrogen.

Sulphur unites with chlorine to form a volatile liquid, which exhibits a red colour when viewed by reflected light, and a greenish-yellow tint by transmitted light. This compound called *Chloride of Sulphur* may be formed by passing a current of chlorine through flowers of sulphur, or by heating the latter in dry chlorine gas. It has a strong peculiar smell, and a hot acid taste; but it does not affect vegetable blue colours without water be present, which decomposes it. It is also decomposed by many other substances; but it readily dissolves sulphur and phosphorus, and holds them in solution. It decomposes ammonia, and likewise alcohol and ether, and is decomposed by mercury, heat being given out, sulphur deposited, and chloride of mercury formed.

Sulphur combines with iodine when they are exposed together to a gentle heat, and the product is a black crystallizable substance named *Iodide of Sulphur*. It becomes decomposed by a degree of heat not much beyond that required for its formation, the iodine in this case being driven off in the form of vapour.

Bromide of Sulphur is produced when bromine and sulphur are digested together. This compound is a red liquid, fuming when exposed to air, which scarcely acts on paper tinged with litmus, unless moisture be present, when it changes the blue colour to red. It acts violently on water at the boiling point, sulphuretted hydrogen being given out, and hydrobromic and sulphuric acids formed.

Sulphuret of Carbon may be obtained by passing the vapour of sulphur through a porcelain tube, containing small pieces of charcoal, quite free from moisture, and made red-hot, placing the tube somewhat inclined across a chafing-dish, or by distilling about six parts of yellow iron pyrites (bisulphuret of iron) with one of charcoal; and the product in either case may be suffered to fall from the lower end of the tube into a jar of water, the tube dipping beneath its surface. The sulphuret of carbon passing over in a state of vapour, will be condensed by the water to a liquid, which may be purified by redistillation, at a low temperature, over chloride of calcium (muriate of lime). The compound thus obtained is a colourless, transparent fluid, with a pungent and somewhat aromatic taste, but a most nauseous and fetid smell. It is highly volatile, boils at a temperature of about 106°, and has never yet been congealed by artificial cold. Its specific gravity is 1.272. From its extreme volatility it has been employed with advantage to produce a very low temperature by evaporation. If the bulb of a thermometer be covered with lint wetted with this liquid, the mercury will sink rapidly from 60° to zero of Fahrenheit; and under the exhausted receiver of an air-pump, the temperature may be reduced even to 80° below zero, so that mercury may by this means be readily congealed. Sulphuret of carbon is not soluble in water, but mixes with alcohol and ether, and also with oils; and it dissolves sulphur, phosphorus, and camphor. It is inflammable, taking fire in the air at a low temperature, and burning with a blue flame; and its combustion in oxygen gas produces sulphurous and carbonic acids.

Sulphuret of Phosphorus.—Sulphur unites with phosphorus, when it is added in small quantities to phosphorus melted in water at a temperature of about 150°. It may be also formed by fusing together those inflammable bodies in an exhausted vessel. The compound is a reddish-brown crystallizable substance, which becomes fluid at about 40°. It does not readily decompose water, but it is more inflammable than phosphorus, and may be used like the oxide of phosphorus, for lighting matches.

Selenium.

This is a rare and singular substance, discovered within the last twenty years, by Professor Berzelius, while examining sulphuric acid, manufactured from pyrites (sulphuret of iron), procured at Fahlun, in Sweden. Selenium, like sulphur, is capable of subsisting under the solid, liquid, or gaseous form; being a solid at common temperatures, and at the heat of above 100° becoming liquid. It was observed, that the sulphuric acid obtained from the pyrites of Fahlun, deposited a reddish matter, which in burning gave out a particular smell, and which consisted principally of sulphur, having however mixed with it a very minute quantity of selenium. This substance has been since found in several of the metallic ores from the Hartz mines, and among some of the volcanic products of the Lipari Islands; and in England, in the pyrites of the Isle of Anglesey.

The processes for obtaining it in a pure state are operose and difficult, when it is necessary to seperate it from the substances with which it is naturally found in combination; but it may be most readily procured by decomposing one of its compounds with oxygen (selenic acid). Selenium in the state of powder has a deep red colour. Its particles when compressed unite; and when warm it is very ductile, and may be drawn out into fine threads, the colour of which is red if viewed by transmitted, and grey by reflected light. It boils at a temperature of about 600°, and is converted into a yellow vapour, forming when condensed dark drops, which run together like quicksilver; and when heated in large vessels, or in the open air, it forms a sublimate like flowers of sulphur, but of a red colour. When heated in the flame of a candle by a stream of air from a blowpipe, it yields a peculiar strong smell, resembling that of horseradish. It presents some analogies with sulphur, but is about double the specific gravity of that substance, and is a non-electric, whence some chemists have been disposed to reckon it among the metals. It differs from bodies of that kind, however, in being a non-conductor of electricity, and a very imperfect conductor of heat.

With oxygen selenium forms at least two compounds, one called Selenious Acid and the other Selenic Acid.

Selenious Acid.—When a current of oxygen gas is passed over selenium heated to its boiling-point, it burns with a pale blue-green flame, and this acid sublimes, and may be condensed if received in a cold vessel, forming long, brilliant, prismatic crystals. It has a hot, sour taste, and a sharp odour. It dissolves in warm water, and also in alcohol. It forms precipitates in the solutions of silver and of lead, and combines in various proportions with several salifiable bases.

Selenic Acid may be obtained by dissolving one part of selenium in three or four parts of pure nitric acid, and the mixture being boiled, the selenium will decompose the nitric acid, and a solution of selenic acid will be formed, which may be evaporated to dryness in a porcelain capsule; or if the solution be only concentrated, the acid will crystallize in hexaedral prisms. Selenic acid has no smell, but a strong sour taste. It powerfully attracts water, and gives out much heat when mixed with it. It reddens vegetable blues, and when exposed to heat it becomes volatilized without decomposition. When it is boiled with muriatic acid, selenious acid and chlorine are evolved, and the selenio-muriatic acid which is formed dissolves gold in the same manner with the nitro-muriatic. Zinc and iron are dissolved by this acid, while hydrogen is given off; and copper dissolves with the production of selenious acid. It likewise dissolves gold, but not platina. The affinity of selenic acid for the salifiable bases appears to be little inferior to that of sulphuric acid; but the compounds it forms with them require further examination.

Selenium forms two compounds with chlorine. *Protochloride of Selenium*, which may be obtained by passing chlorine gas over selenium, is a brown liquid, heavier than water; and when exposed to the action of water, decomposition takes place, and muriatic and selenious acids are formed. The protochloride may be changed by the addition of chlorine into perchloride, which is a white, solid, crystallizable substance, forming with water a colourless sour solution.

Selenium likewise combines with hydrogen, forming a gaseous compound termed *Hydroselenic Acid*, or *Seleniuretted Hydrogen*. It may be most readily obtained by dissolving seleniuret of iron in muriatic acid. This compound dissolves in water, and the solution, which gradually acquires a reddish tint, has somewhat the smell and taste of sulphuretted hydrogen: it reddens litmus paper, and communicates a brown tint to the skin. Hydroselenic acid is readily decomposed by the combined action of air and water; and it is therefore absorbed by moist substances, to which it gives a red colour. A thin mass of caoutchouc may thus be stained red throughout its substance. This gas acts most injuriously on the mucous membranes; and therefore the eyes, nose, and trachea, should be carefully guarded against its reception, while making experiments on it, as its operation is not only painfully stimulating, but might also be productive of serious mischief.

METALLIC ELEMENTS.

The metals form in some respects a heterogeneous collection of substances: among them are to be found the heaviest bodies with which we are acquainted, gold and platina; while, on the contrary, potassium and sodium are inferior in specific gravity to water; gold, silver, platina, and palladium, are in the highest degree malleable and ductile; but antimony, cobalt, manganese, and arsenic, with some others are so brittle that they may be reduced to powder by percussion. The metals also differ greatly one from another in hardness, colour, and capacity for yielding sound; and though they are all conductors of heat and electricity, they vary as to their relative power of conduction. Mercury, as is well known, is at the common temperature of the atmosphere a liquid, and it requires a degree of cold far below that of freezing water to reduce it to the solid state: platina has the opposite property of remaining solid when exposed to the utmost heat of a smelting furnace, though it may be fused by the flame of an oxy-hydrogen blowpipe, or by means of a Voltaic battery. Other metals display intermediate degrees of fusibility; thus potassium and sodium melt at temperatures below that of boiling water, tin becomes fused at 442° Fahrenheit, bismuth at 497°, and lead at 612°; and an alloy composed of these three metals in certain proportions dissolves at about the boiling-point of water. It appears probable that silver melts at 1873°, gold at 2016°, cast iron at 2786°, and, according to MM. Clement and Desormes, soft or pure iron at 3945°; but these last estimates are rendered somewhat questionable by the difficulty of measuring the temperature of intensely-heated bodies.

As to their decidedly chemical properties, the metals exhibit much diversity. All of them are capable of entering into combination with oxygen, chlorine, and sulphur; but in their respective modes of action, and the results of their several affinities for those bodies, they manifest as much contrariety as with regard to their physical properties.

Some metals have so strong an attraction for oxygen that they decompose water at all temperatures, and become oxidated by mere exposure to atmospheric air, as is the case with potassium, sodium, and calcium; others decompose water but slowly except at a red heat, as manganese, zinc, and iron. There are several others, including arsenic, bismuth, copper, and cobalt, which are incapable of decomposing water at any temperature, but they absorb oxygen from the air when strongly heated. Mercury, lead, nickel, and osmium, do not decompose water, but become oxidated at certain temperatures; and when their oxides are more intensely heated, they are partially or wholly reduced to the metallic state. And there is yet another class of metals, which neither abstract oxygen from air or water at any temperature, as platina, gold, silver, and palladium; and which, when their oxidation has been effected indirectly by means of certain acids, are reduced to the metallic state at a heat below redness.

The indications thus furnished by the relative action of oxygen on the various metals, have been employed by M. Thenard, in the formation of a classical arrangement of those bodies, which has been adopted by some other writers; but it is liable to objections, and the discoveries that have been made since it was proposed would furnish ground for several modifications and additions. The method of classification proposed by Professor Berzelius, drawn from the electro-negative and electro-positive properties of the metals respectively, when it becomes completely developed, will present the greatest advantages; and it has already been applied to the arrangement of native mineral compounds with great success, contributing much to the elucidation of their nature, and their relations to various other bodies. Connected with this distinction of the metals into those which are electro-negative and those which are electro-positive, is that which may be deduced from the character of their compounds. The electro-negative metallic bodies, arsenic, tellurium, vanadium, and others, when united with a relatively large proportion of oxygen, constitute bodies which display the general properties of acids, forming sur-compounds (salts) with metallic oxides. Among the electro-positive metals are those whose combinations with oxygen most decidedly act the part of bases in the formation of salts. Hence all the metals now known may be distributed in three classes: 1. Those which form acids with oxygen, namely, arsenic, antimony, columbium, titanium, chrome, molybdenum, tellurium, tungsten, vanadium, uranium, manganese, cobalt, and tin. 2. The metallic bases of the alkalies and earths, potassium, sodium, lithium, baryum, calcium, strontium, magnesium, aluminum, zirconium, glucinum, yttrium or ittrium, and thorium. 3. Those metals whose combinations with oxygen are not regarded as acids, alkalies, or earths, namely, iron, nickel, zinc, cadmium, cerium, lead, copper, bismuth, mercury, silver, gold, platina, palladium, rhodium, iridium, and osmium.

This is to be considered as only a provisional arrangement, admitting of alteration to suit it to the future progress of discovery. Some of the metals of the third class perhaps ought even now to be transferred to the first, as gold, the peroxide of which is capable of combination with barytes, and has therefore by some been styled auric acid. The distinction between some of the metals of the second and third classes also is but inconsiderable. The characters of the bodies in the first and second classes are sufficiently contrasted; and it is not improbable that those of the third class may be ultimately found to be referable to one or other of the former classes.

Binary Combinations of the Metallic Elements of the First Class with Oxygen, Sulphur, and some other Non-metallic Elements.

Arsenic.

Arsenious Acid, 2 Ars. 3 Ox.
Arsenic Acid, 2 Ars. 5 Ox.
Arseniuretted Hydrogen.
Red Sulphuret of A. (Realgar), 2 Ars. 2 S.
Yellow Sulphuret of A. (Orpiment), 2 Ars. 3 S.
Persulphuret of A., 2 Ars. 5 S.
Chloride of A., 2 Ars. 3 Ch.
Perchloride of A., 2 Ars. 5 Ch.

Antimony.

Oxide of A., 2 Ant. 3 Ox.
Antimonious Acid, 2 Ant. 4 Ox.
Antimonic Acid, 2 Ant. 5 Ox.
Subsulphuret of A., 2 Ant. 3 S.
Sulphuret of A., 2 Ant. 4 S.
Persulphuret of A., 2 Ant. 5 S.

Antimony *continued.*

Subchloride of A., 2 Ant. 3 Ch.
Chloride of A., 2 Ant. 4 Ch.
Perchloride of A., 2 Ant. 5 Ch.

Columbium.

Oxide of C., 1 Col. 2 Ox.
Columbic Acid, 1 Col. 3 Ox.
Sulphuret of C., 1 Col. 3 S.
Chloride of C., 1 Col. 3 Ch.

Titanium.

Oxide of T.
Titanic Acid, 1 Tit. 2 Ox.
Sulphuret of T., 1 Tit. 2 S.
Chloride of T., 1 Tit. 2 Ch.

Chrome.

Oxide of C., 2 Chr. 3 Ox.
Deutoxide of C., 1 Chr. 2 Ox.
Chromic Acid, 1 Chr. 3 Ox.
Sulphuret of C.

Molybdenum.

Oxide of M., 1 Mol. 1 Ox.
Peroxide of M., 1 Mol. 2 Ox.
Molybdic Acid, 1 Mol. 3 Ox.
Sulphuret of M.
Chloride of M., 1 Mol. 1 Ch.
Bichloride of M., 1 Mol. 2 Ch.
Perchloride of M., 1 Mol. 3 Ch.

Tellurium.

Tellurous Acid, 1 Tel. 2 Ox.
Telluric Acid, 1 Tel. 3 Ox.
Telluret of Hydrogen, 1 Tel. 1 H.

Tellurium *continued.*

Sulphuret of T., 1 Tel. 2 S.
Persulphuret of T., 1 Tel. 3 S.
Chloride of T., 1 Tel. 1 Ch.
Bichloride of T., 1 Tel. 2 Ch.

Tungsten.

Oxide of Tungsten, 1 Tun. 2 Ox.

$$\left.\begin{array}{l}\text{Tungstic, or}\\ \text{Scheelic Acid,}\end{array}\right\}\text{1 Tun. 3 Ox.}$$

Sulphuret of T., 1 Tun. 2 S.
Persulphuret of T., 1 Tun. 3 S.
Chloride of T., 1 Tun. 2 Ch.
Perchloride of T., 1 Tun. 3 Ch.

Vanadium.

Oxide of V., 1 V. 1 Ox.
Peroxide of V., 1 V. 2 Ox.
Vanadic Acid, 1 V. 3 Ox.
Sulphuret of V., 1 V. 2 S.
Persulphuret of V., 1 V. 3 S.
Chloride of V., 1 V. 2 Ch.
Perchloride of V., 1 V. 3 Ch.

Uranium.

Oxide of U., 1 U. 1 Ox.

$$\left.\begin{array}{l}\text{Uranic Acid, or}\\ \text{Peroxide of U.}\end{array}\right\}\text{2 U. 3 Ox.}$$

Sulphuret of U., 2 U. 3 S.

Manganese.

$$\text{Oxides of M.}\begin{cases}\text{1 Man. 1 Ox.}\\ \text{1 Man. 2 Ox.}\\ \text{2 Man. 3 Ox.}\\ \text{3 Man. 4 Ox.}\\ \text{4 Man. 7 Ox.}\end{cases}$$

Manganese *continued*.

Manganeseous Acid, 1 Man. 3 Ox.
Manganesic Acid, 2 Man. 7. Ox.
Chloride of M., 1 Man. 1 Ch.
Perchloride of M.
Sulphuret of M., 1 Man. 1 S.

Cobalt.

Oxide of C., 1 Cob. 1 Ox.
Peroxide of C., 2 Cob. 3 Ox.
Cobaltic Acid, 1 Cob. 2 Ox.
Chloride of C., 1 Cob. 1 Ch.
Sulphuret of C., 1 Cob. 1 S.
Persulphuret of C., 1 Cob. 2 S.

Tin.

Oxide of T., 1 Tn. 1 Ox.
Stannic Acid, or Peroxide of T. } 1 Tn. 2 Ox.
Hemichloride of T., 2 Tn. 1 Ch.
Chloride of T., 1 Tn. 1 Ch.
Bichloride of T., 1 Tn. 2 Ch.
Sulphuret of T., 1 Tn. 1 S.
Bisulphuret of T., 1 Tn. 2 S.
Phosphuret of T., 3 Tn. 2 Ph.

Arsenic.—The substance popularly known under the designation of arsenic is the arsenious acid, one of the compounds of the metal with oxygen. In the metallic or uncombined state arsenic is of a greyish-white colour, shining brightly when untarnished; but as it readily attracts oxygen from the air, its surface soon becomes dull when exposed to it; but it will retain its lustre if kept under water or alcohol. It is moderately hard, and very brittle. Arsenic fuses readily, and becomes volatilized if heated in a close vessel to about 360°. When thrown on a red-hot iron, or otherwise heated in contact with atmospheric air, it burns with a blue flame, subliming in the form of a white vapour, having an odour like garlic. The sublimate when cooled crystallizes in octaedrons, consisting of arsenious acid, formerly called white oxide of arsenic. This substance, well known as a most virulent poison, generally occurs in the state of a compact saline mass, or heavy white powder. It is very sparingly dissolved by cold water; but 100 parts of boiling water will dissolve 7.77 parts of the acid, more than half of which remains suspended after the liquid becomes cool. The arsenic acid, which is a deliquescent, colourless substance, is also poisonous. Arseniuretted hydrogen is a strongly poisonous, inflammable gas. Both the sulphurets of arsenic occur as native minerals. Arsenic becomes inflamed when introduced in a divided state into chlorine gas, and burns with great splendour.

Antimony.—What is termed crude antimony in commerce is the sulphuret of this metal, which is found in the native state. Metallic antimony is a shining, hard, and brittle substance, somewhat the colour of silver. It has a laminated and imperfectly crystalline texture. When exposed to the air it loses its lustre, but is otherwise little altered. If rubbed on the fingers, it gives out a peculiar smell and taste. It becomes fused at 810°, and sublimes in a white heat, combining with oxygen. The powdered metal takes fire when thrown into chlorine gas, and burns with a bright white flame. The product is a liquid, which becomes concrete at common temperatures, constituting the chloride, formerly named, from its consistence, butter of antimony. The perchloride is a volatile, transparent, fuming liquid. Several preparations of this metal are used in medicine, of which the best known and most valuable is emetic tartar, or antimoniated tartrate of potash.

Columbium.—This is a dark grey metal, very difficult of fusion, and extremely hard and brittle. It is not altered by exposure to the air; but it burns at a red heat, forming a whitish oxide. It is scarcely at all soluble in any of the acids except the fluoric, in which it dissolves with the evolution of heat, and the disengagement of hydrogen gas.

Titanium.—Dr. Wollaston found this metal in the slag of an iron furnace at Merthyr Tydvil, in South Wales, in the state of small cubic crystals, of a red or copper colour, and so hard as to scratch rock crystal. It is infusible by a common blowpipe, but becomes oxidated by continued heat, a purple film forming on its surface. No acid acts on it; but if it be heated with nitre, oxidation readily takes place. The oxide of titanium has been used for painting on porcelain.

Chrome, or *Chromium*.—This metal obtained its name from the varied colours of its salts.* It is a white and very brittle metal, susceptible of a high polish, and, according to Richter, slightly magnetic. It can be fused but imperfectly at a very high temperature. No acids appear to act on it except the fluoric, which dissolves it readily. When heated with nitre it combines with oxygen, forming chromic acid. This acid is of a deep red colour; and the oxide of chrome exhibits a green colour. Some of the coloured gems owe their beautiful tints to this metal; and it furnishes some fine pigments for enamel painting and calico-printing.

Molybdenum.—This metal is said to have been obtained in the state of small grains of a brittle texture, and of a light grey colour; but it may be questioned whether it has undergone perfect reduction, as it is exceedingly difficult of fusion. When heated in contact with oxygen gas or atmospheric air, it becomes converted into a white crystalline sublimate, which is the molybdic acid.

Tellurium.—This is one of the most important of the acidifiable metals, the nature and properties of which have been illustrated by the elaborate researches of Berzelius.† The metal is of a bright grey colour, and has a foliated texture: it is brittle, readily fusible, and very volatile. When heated to full redness in a close vessel, it sublimes in the form of a yellow gas, which condenses in drops, and becomes crystallized on cooling. The smell of its vapour is peculiar, slightly resembling that of selenium.‡ Tellurium is soluble in the nitric and the nitro-muriatic acids. Its combination with oxygen in the proportion of 1 T. + 2 Ox. forms an acid capable of existing in two states, the tellurous acid and the paratellurous acid; and the compound of 1 T.+3 Ox. has corresponding properties, forming the telluric and the paratelluric acids.* The combination of tellurium with hydrogen is a gas, which, like sulphuretted hydrogen, manifests the properties of an acid.

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* From the Greek Χρῶμα, *colour*.

† See Johnston on Chemistry in Report of British Association, 1832, p. 471.

‡ Id. p. 472. The odour of this metal, or rather of the vapour of tellurous acid, has been compared with that of radishes. See Children's Essay on Chemical Analysis, p. 67.

Tungsten.—This metal is distinguished for its specific gravity, being about 17½ that of water. It is of an iron-grey colour, very hard, brittle, and difficult of fusion. When heated in atmospheric air it combines with oxygen to form tungstic oxide, a brown or chocolate coloured powder. This oxide exposed to a red heat, and agitated in an open vessel, absorbs more oxygen, and becomes tungstic acid, which is a yellow powder, but acquires a greenish hue by long exposure to the rays of the sun.

Vanadium.—The properties of this metal most nearly correspond with those of chrome, and in a natural arrangement of the metallic elements, it might be placed between chrome and molybdenum. In colour and lustre it resembles the latter metal. "It is characterized by giving, in the form of an oxide, blue salts with acids, with oxygen forming a peculiar acid, which fuses at a red heat without decomposition, and on cooling is reddish-brown and crystalline, and which gives with bases, colourless neutral, and orange-coloured acid salts. Before the blowpipe it behaves itself like chromium, with this characteristic difference, that the green colour with borax can in the oxidizing flame be changed into a pale yellow."†

Uranium.—This metal is of a greyish-brown colour, possessing considerable lustre, brittle, and very difficult of fusion. It does not tarnish in the air at common temperatures, but when made red-hot in an open vessel, it becomes oxidated, forming a dark green or blackish powder. The compound of 2 U. + 3 Ox., is a yellow powder, used in painting porcelain, and which acts as an acid, forming a salt with barytes.

Manganese.—This metal, in some of its properties, resembles iron. It may be obtained by exposing the black oxide, with charcoal powder and oil, to a most intense heat in a wind furnace, and the metal will then be found in small globules, or in the form of an imperfect button, at the bottom of the crucible. It is of a dusky-whitish colour, and finely granular texture, softer than cast iron, and very brittle. It is difficult of fusion, and is readily acted on by the air, tarnishing, and at length crumbling into a brown powder. When heated in oxygen gas, it undergoes combustion, and it decomposes the vapour of water at a red heat. The peroxide, 1 M. + 2 Ox., from its colour styled black oxide of manganese, is frequently found native, and is the general source from which the metal and its compounds are procured. No change is produced on it by exposure to the air, but the variety of native oxide, called Black Wad, has the property of spontaneous inflammation, when well dried, and kneaded with linseed oil. It is insoluble in water, and does not combine with acids or alkalies; but such acids as appear to dissolve it, reduce it to the state of protoxide, with which salts are formed.

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* See Johnston's Rep. on Chem., pp. 472, 473.

† Id. p. 469.

When the peroxide of manganese is mixed with an equal weight of nitrate of potash, and exposed to a red heat, a green mass is obtained, which being put into water, furnishes a solution, the colour of which successively becomes green, blue, purple, and red, and ultimately disappears entirely; whence it has been called the *chameleon mineral*. The experiment may be varied by putting equal quantities of the mixture of the peroxide and nitre into two glasses, and pouring on one hot, and on the other cold water; when the former solution will exhibit a fine green colour, and the latter a deep purple, and the shades will vary with the alteration of temperature.*

Cobalt.—The metallic nature of this substance was first recognised about one hundred years ago, but its oxide has been used in making coloured glass since 1540. Cobalt is of a reddish-grey colour, and a fibrous or laminated texture, brittle, and difficultly fusible. Like iron and nickel, it may be rendered magnetic. Air or water do not act on it at a low temperature, but when heated to redness in an open vessel, it forms an oxide of a very deep blue colour, and if the heat be intense, the metal takes fire, and burns with a red flame. The chloride of cobalt combined with water, forms Hellot's sympathetic ink, which may be prepared by digesting the oxide of this metal in muriatic acid, and adding water till the liquid becomes of a pale rose colour. Any thing written on paper with a clean pen dipped in this solution, will be invisible till it is slightly heated, when the writing will appear of a bright green tint, which vanishes as the paper cools, and may be renewed at pleasure; but if once strongly heated, the characters become permanent. Acetate of cobalt (the salt formed by oxide of cobalt and acetic acid) dissolved in water constitutes an excellent sympathetic ink, which may be used like the preceding; but it gives to paper a beautiful azure instead of a green tint when heated. The oxide of cobalt, in combination with silicic acid and potash, forms smalt, and other blue pigments used in the arts.

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* See Johnston's Rep. on Chem., pp. 477, 482.

Tin.—This is one of the metals which appear to have been known to the ancient Greeks and Romans, who obtained it from Spain and Britain. Its general appearance is well known, tin-plate, consisting of sheets of iron coated with tin, being used for a multiplicity of purposes; and tinfoil (leaf-tin), employed to line tea-chests, and wrap up articles which require to be protected from the air. Tin is not very hard, nor ductile, but extremely malleable; and when sheet-tin is bent suddenly, it emits a peculiar sound, called by the French *cri d'étain*: this metal has also a characteristic odour, and a faint but disagreeable taste. It is not affected by water at common temperatures, but becomes tarnished by exposure to the air. If steam be passed over tin heated to redness, it decomposes the water, absorbing oxygen, and the hydrogen is given off in the gaseous state. The compound of 1 T. + 2 Ox., called peroxide of tin, is capable of combination with alkalies, thus manifesting the properties of an acid. When fused with glass, it forms a milk-white enamel, useful for technical purposes. The substance called in commerce tin putty, is an impure oxide of tin. This metal burns in oxygen gas, when heated below its fusing-point, and it is soluble in the sulphuric, nitric, and muriatic acids. Bichloride of tin is a colourless liquid, called the fuming liquor of Libavius, from its alleged discoverer, a chemist of the seventeenth century. Combinations of tin with chlorine are used in dyeing and calico-printing, and with the solution of gold in nitro-muriatic acid, to form the purple powder of Cassius, a pigment employed in ornamenting porcelain. The bisulphuret of tin is a substance of a shining yellow colour, and a flaky structure, which was formerly called Mosaic Gold (*Aurum Musivum*).

Binary Combinations of the Metallic Elements of the Second Class with Oxygen and Chlorine.

Potassium.

Protoxide of P. (Potash), 1 Pm. 1 Ox.
Peroxide of P., 1 Pm. 3 Ox.
Chloride of P., 1 Pm. 1 Ch.

Sodium.

Protoxide of S. (Soda), 1 Sod. 1 Ox.
Peroxide of S., 1 Sod. 2 Ox.
Chloride of S. (Marine Salt), 1 Sod. 1 Ch.

Lithium.

Oxide of L. (Lithia), 1 L. 1 Ox.
Chloride of L., 1 L. 1 Ch.

Baryum.

Protoxide of B. (Barytes), 1 B. 1 Ox.
Peroxide of B., 1 B. 2 Ox.
Chloride of B., 1 B. 1 Ch.

Calcium.

Protoxide of C. (Lime), 1 Cal. 1 Ox.
Peroxide of C., 1 Cal. 2 Ox.
Chloride of C. (Muriate of Lime), 1 Cal. 1 Ch.

Strontium.

Protoxide of S. (Strontia), 1 Str. 1 Ox.
Peroxide of S., 1 Str. 2 Ox.
Chloride of S., 1 Str. 1 Ch.

Magnesium.

Oxide of M. (Magnesia), 1 Mag. 1 Ox.
Chloride of M., 1 Mag. 1 Ch.

Aluminum.

Oxide of A. (Alumina), 2 Al. 3 Ox.
Chloride of A., 2 Al. 3 Ch.

Zirconium.

Oxide of Z. (Zircon Earth), 2 Zir. 3 Ox.

Glucinum.

Oxide of G. (Glucina), 2 Gl. 3 Ox.

Yttrium.

Oxide of Y. (Yttria), 1 Y. 1 Ox.

Thorium.

Oxide of T. (Thorina), 1 Th. 1 Ox.

Potassium.—This metal is the basis of potassa, or, as it was formerly called, the Fixed Vegetable Alkali, which was discovered by Sir H. Davy to be protoxide of potassium. It may be procured by placing a thin plate of pure caustic potash, slightly moistened, between two disks of platina, connected with the opposite wires of a powerful Voltaic battery, when the alkali will become fused and afterwards decomposed, its oxygen being evolved at the positive wire, while the metal, in small shining globules, will make its appearance at the surface connected with the negative wire. Potassium may also be obtained by passing melted potash through a red-hot gun-barrel, containing fragments of iron, which at a very high temperature, will decompose the alkali, by attracting its oxygen, and thus the metal will be set free as before. The affinity of this metal with oxygen is so great, that it decomposes most bodies which contain it, even at very low temperatures; and hence when potassium comes in contact with atmospheric air or water, it immediately absorbs oxygen from either of those fluids, and protoxide of potassium or potash is thus produced. Potassium, therefore, cannot be preserved without being secured from the contact of air and water; but it may be kept immersed in ether, or included in exhausted glass tubes hermetically sealed.

Potassium at 32° Fahrenheit, is a hard, brittle solid, of a crystalline structure, and of a white colour, like silver. At about 50° it becomes malleable and ductile, having nearly the consistency of soft wax, and in that state its specific gravity is about 0.85; at 150° it is perfectly fluid, and at a bright red heat it sublimes without decomposition, in the form of a green vapour. It is a good conductor, both of heat and electricity. When this metal is heated in air or oxygen gas, it burns with a brilliant white flame, and is converted into an orange-coloured substance which, on cooling, appears in the state of crystalline scales. This is the peroxide of potassium. The protoxide of potassium, or caustic potash, has a most powerful affinity for water, which it readily absorbs from the air; and thus forms a definite compound, called hydrate of potash, composed of 1 potash + 1 water. The common potash and pearlash of the shops consist of this alkali combined with carbonic acid, forming carbonate of potash. This salt is commonly obtained by evaporating the ley produced by steeping wood-ashes in water. The decomposition of the carbonate of potash is effected by means of caustic lime, which having a stronger attraction for carbonic acid than potash has, it attracts the acid, and sets free the alkali in the state of hydrate of potash. This substance, when purified, is white, acrid, and corrosive, destroying the texture of animal and vegetable substances. It speedily absorbs moisture and carbonic acid from the air, but it may be crystallized in octaedrons, by keeping a strong solution of it in water for some time, in close vessels. It reddens substances coloured by turmeric, changes vegetable blues to green, and neutralizes acids without any effervescence. It enters into combination with fat oils, forming soft soaps.

When small quantities of potassium are introduced into chlorine gas, intense inflammation takes place, and the chloride is produced. This is a white saline substance, of a bitter disagreeable taste, readily soluble in water, from which it may be procured by evaporation in cubic crystals. It was formerly supposed to be a compound of muriatic acid and potash, and it was long used in medicine under the names of digestive salt of Sylvius, and regenerated sea-salt. Potassium has a stronger affinity for chlorine than for oxygen, since both its oxides are decomposed by chlorine gas.

Potassium enters into combination with iodine and with bromine, and the iodide of potassium is sometimes used in medicine. Potassium also unites with hydrogen, sulphur, selenium, phosphorus, and carbon, to form peculiar compounds. Alloys are formed by the combination of potassium with various other metallic bodies. The amalgam of potassium, or combination of this substance, with mercury, may be readily formed, by mixing them together at the usual temperature of the air. This amalgam may also be produced by placing a thin mass of mercury in the bottom of a flat glass vessel, about two inches in diameter, and pouring over it a strong solution of caustic potash, then on connecting an iron wire from the negative pole of a Voltaic battery with the mercury, and a platina wire from the positive pole with the alkaline solution, into which it must be dipped so as not to touch the surface of the mercury, an amalgam will be formed with such rapidity, that more than 1200 grains of mercury will become combined into a solid alloy with the potash in twenty-four hours. This amalgam has the property of dissolving all other metals. Potassium likewise combines with gold, silver, and copper; but when any of its alloys are thrown into water they become decomposed, potash being formed, which dissolves in the water, and the other metal is set free.

Sodium.—This metal, which is the basis of soda or mineral alkali, greatly resembles potassium, both in its physical and chemical properties. It may be obtained from soda by similar processes to those already described for the decomposition of potash, only it is necessary to employ a stronger electric power, or a higher degree of heat. Sodium is a soft malleable metal, which does not become brittle like potassium at 32°, since at that temperature globules of it may be welded together by pressure. It is rather heavier than potassium, its specific gravity being 0.97. In colour it resembles lead, but tarnishes on exposure to a moist atmosphere. Its fusing-point is about 190°, and it is volatile at a white heat; but if heated in contact with air, it burns with a white light, accompanied with red sparks. In consequence of its powerful affinity for oxygen, it must like potassium, be preserved under ether or naphtha. Soda, or the protoxide of sodium, combines with water, forming hydrate of soda, which is the mineral alkali or natron of commerce.

The combination of sodium with chlorine (chloride of sodium), is the substance generally known as common or marine salt. This body, which exists largely in nature, especially in the state of rock-salt and in solution in sea-water, was formerly supposed to be a compound of muriatic acid and soda, and hence it was called muriate of soda. It is now known, however, to be a substance of a different class from the proper salts, or compounds of acids and alkalies, and, upon the whole, it may be considered as having a closer analogy with the alkalies than with the neutral salts. It may be produced artificially by heating sodium in chlorine gas, when the metal burns, forming a white compound, which is the chloride of sodium. This chloride becomes decomposed by heating it with potassium, and thus the sodium is set free and chloride of potassium produced. If protoxide of sodium be exposed to heat, in chlorine gas, oxygen will be evolved, and chloride of sodium formed. When the protoxide is heated in hydrochloric (muriatic acid) gas, a mutual decomposition will take place, and the products will be the chloride and water. The chloride of sodium crystallizes in regular cubes, which decrepitate, or fall into pieces with a crackling noise when heated; and if the heat be raised to redness, the crystals fuse without decomposition, and on cooling become congealed into a hard white mass. This substance, though readily soluble in water, is almost insoluble in alcohol. Its general properties, and the numerous purposes to which it is applied, are too well known to require specification.

Sodium unites with iodine and bromine, and among the combustibles, with sulphur, selenium, and phosphorus, but not with hydrogen. It forms alloys with most, if not all, the metals.

Lithium.—This is a metallic substance comparatively of rare occurrence, having hitherto been found only in the petalite, spodumene, lepidolite, some kinds of feldspar, and a few other minerals, and in certain waters in Bohemia. In these bodies it exists in the state of an oxide, called lithia, which exhibits properties partly resembling those of the earths, and partly those of the alkalies. The oxide of lithium may be decomposed, like potash and soda, by Voltaic electricity, and the product is a brilliant white and highly combustible metallic substance, bearing much resemblance to sodium; but its properties have hitherto been very little investigated, in consequence of the scarcity of its compounds. Chloride, iodide, fluoride, and sulphuret of lithium have been obtained, but their respective properties are but imperfectly known. Oxide of lithium (lithia) differs from potash and soda in its power of saturating a greater quantity of any acid, and in forming difficultly soluble salts with the carbonic and phosphoric acids. It may be distinguished from the alkaline earths (lime and barytes) by the greater solubility of its saline compounds with the sulphuric and oxalic acids; and by its acting in the state of carbonate upon vegetable colours, like potash and soda.

Baryum.—This metallic body may be obtained by negatively electrizing its oxide (which is the earth called barytes) in contact with mercury. An amalgam will thus be gradually formed, from which the mercury may be expelled by heat. The metal is of a dark grey colour, with a lustre inferior to that of cast-iron, and it is about twice as heavy as water. It speedily absorbs oxygen when exposed to air, crumbling into a white powder, which is the protoxide of baryum; and when thrown into water it suddenly decomposes that fluid, hydrogen being evolved, and the oxide which is formed dissolving in the water. The protoxide of baryum (barytes) is not unfrequently found among minerals, in combination with either the carbonic, or the sulphuric acid, with the latter of which it constitutes the substance called ponderous spar (*terra ponderosa*). Pure barytes has a caustic taste, turns vegetable blue colours green, and neutralizes acids like the alkalies. It is very poisonous, as likewise are all the soluble salts formed of it. It is usually obtained in the state of a grey powder, the specific gravity of which is about 4. It is insoluble in pure alcohol, but very readily soluble in water, and it may be slaked like quicklime, giving out a great quantity of heat during the process. Peroxide of baryum may be produced by heating the protoxide in oxygen gas, which is rapidly absorbed, and a grey compound is formed. This substance is principally deserving of notice, as having been used by M. Thenard in the preparation of oxygenated water, of which some account has been already given.

Baryum unites with chlorine, iodine, bromine, and fluorine, and also with some of the simple combustibles.

Calcium.—This metal was discovered by Sir H. Davy, who procured it in a separate state from lime by the action of a Voltaic battery. It has, however, been obtained in very small quantities, and but little is known concerning its physical properties, except that it has the colour and lustre of silver. When exposed to common air the metal takes fire, and burns with an intense white light, forming protoxide of calcium, or pure lime. The amalgam of calcium thrown into water is decomposed with the evolution of hydrogen, and the oxygen of the water unites with the calcium to form lime. The protoxide of calcium (lime) is a white pulverulent earth, which is one of the most abundant and most important of all natural substances. In the mineral kingdom it forms limestone and other rocks; it is contained in many vegetable products, and also forms the basis of bone and other animal substances. It may be most readily obtained in the state of purity by exposing powdered calcareous spar, or white marble, to a strong red heat. Pure lime, commonly called quicklime, has an acrid and alkaline taste, corrodes animal substances, and changes vegetable blue colours to green. It is very difficultly fusible, but facilitates extremely the fusion of other mineral bodies, as metallic ores, and it is therefore employed as a cheap and powerful flux. It is sparingly soluble in water, and hot water takes up a smaller quantity of it than cold, so that when lime-water is boiled, the lime is precipitated. Lime absorbs moisture from the air, and becomes converted into hydrate of lime, as also happens when it undergoes the process of slaking. Lime may be obtained in a crystalline state by placing lime-water under the exhausted receiver of an air-pump, together with sulphuric acid in another vessel, the water thus becoming slowly evaporated, imperfect hexagonal crystals will be formed, consisting of hydrate of lime.

Calcium is capable of entering into combination with oxygen in two proportions, forming, besides lime, a peroxide or deutoxide. The chloride of calcium, which is formed when pure lime is heated in chlorine, is known in commerce under the names of oxymuriate of lime and bleaching powder, extensively used for various purposes.

Strontium.—This metal may be obtained from the earth called strontia, which is an oxide of strontium, by a process analogous to that described for the production of baryum. It possesses but a moderate degree of lustre, is difficult of fusion, and not volatile. It is converted into an oxide by exposure to atmospheric air, and it also decomposes water. The oxide of strontium, or strontia, derives its appellation from its having been found in a mineral, first discovered in a lead-mine at Strontian, in Argyllshire, in which the earth is combined with carbonic acid. Strontia is a grey pulverulent mass, having decidedly alkaline properties. It may be slaked with water, giving out much heat, and forming a solid hydrate, which is readily soluble in boiling water, and deposits crystals on cooling. When immersed in alcohol, it causes the vapours of that fluid to burn with a bright red flame. Its taste is acrid; but it differs from barytes in not being poisonous. Strontium unites with chlorine and some other bodies; but its compounds have been but slightly examined.

Magnesium.—Sir H. Davy was foiled in an attempt to procure magnesium by exposing the earth, in its pure state, to the action of the Voltaic battery; but he succeeded better by galvanizing solutions of the sulphate or nitrate of magnesia, in contact with mercury. By this means a metallic solid was obtained, which sunk rapidly in water, though surrounded by globules of gas, producing magnesia; and it quickly changed in air, becoming covered with a white crust, or falling into a fine powder, which proved to be magnesia. The metal has since been obtained by M. Bussy from the action of potassium on chloride of magnesium, heated to redness in a porcelain tube. It appeared in the state of small brown scales, which when rubbed in an agate mortar left a metallic trace of a leaden colour. It burns, when strongly heated, with a red light, forming magnesia.

The oxide of magnesium (magnesia), in combination with acids, is abundantly distributed by nature in the mineral kingdom, entering into the composition of various rocks, and being found in considerable quantities in the water of the sea, and of mineral springs. It usually occurs in the state of sulphate, from which the carbonate is prepared, by the addition of carbonate of potash or of soda, when a precipitation takes place. The oxide of magnesium may be obtained pure by exposing carbonate of magnesia to a strong red heat, and the product, known by the name of calcined magnesia, is frequently used in medicine. It is a soft, white, infusible powder, having neither taste nor smell. It slightly reddens turmeric, and has some action on the blue tint of violets, turning it green, like alkalies.

Magnesium combines with chlorine and iodine.

Aluminum.—This metal has been obtained in the state of a finely-divided, grey substance, or in small scales with some metallic lustre. It is very difficult of fusion; and though in the pulverulent state it seems not to conduct electricity, it becomes a conductor when its particles are united. It does not become oxidized by mere exposure to the air; but if heated almost to redness, it burns, forming a white substance, having the general properties of aluminous earth.

The oxide of aluminum or alumine, is found in abundance in the mineral kingdom, constituting, either alone or with other substances, most of the precious stones, as the sapphire, the topaz, the ruby, and the garnet; and it is a constituent part of the hardest and most ancient rocks, and in general also of the superior soil. In the state of clay it is largely used in making tobacco-pipes, bricks, pottery, and porcelain. In combination with sulphuric acid this oxide forms alum, so extensively used in the arts and in medicine. Pure alumine may be obtained by precipitating a solution of alum (sulphate of alumine) in water, by means of ammonia or carbonate of potash. A white, bulky hydrate of alumine will thus be obtained, which, when well washed and exposed to a white heat, will yield the earth in a state of purity. Alumine is a white bland powder, which adheres to the tongue, but has neither taste nor smell, and does not affect vegetable colours. It is insoluble in water, but when moistened with it, forms a ductile, cohesive mass. It has a great affinity for moisture; and after ignition, it will absorb from the atmosphere a quantity of water equal to half its weight. This earth enters into permanent combinations with various animal and vegetable colouring matters, and hence it is of great use in dyeing and calico-printing.

Chloride of aluminum is a yellowish, transparent crystalline substance, which rises in vapour at 212°. When exposed to the air it rapidly deliquesces, forming an acid solution.

Zirconium.—This metal has been obtained from the earth called zircon (oxide of zirconium) by Galvanism, and also by heating potassium with a peculiar salt, fluate of zirconia and potash carefully dried. It is thus procured in the state of a black powder, difficultly soluble in acids, except the hydrofluoric, which readily acts on it, extricating hydrogen. When rubbed between two hard substances it appears in the form of shining scales, of a dark grey colour. If heated in atmospheric air, it burns brightly, forming zircon earth. This earth (oxide of zirconium) is a white insipid powder, which forms salts with different acids, and is sparingly dissolved by the carbonated alkalies; but not by the alkalies in a pure state.

Glucinum.—This metal may be obtained by decomposing its chloride by potassium. It is a grey substance, having but little metallic lustre, and very difficult of fusion. It is not affected by air or water at common temperatures; but when heated, it burns, forming glucina, or oxide of glucinum. This oxide was first discovered in the beryl, and it also occurs in the emerald of Peru, and in the euclase; but has not yet been found in any other minerals. It is a fine, white, soft powder, adhering to the tongue like pure clay. It does not affect vegetable colours, and is insoluble in water; with which, however, it forms a ductile paste. With the acids it combines to form salts, having a sweetish, astringent taste; whence its name, from the Greek word Γλυκυς, *sweet*.

Yttrium.—This is the metallic basis of the earth called yttria or ittria, which was discovered in a mineral found in the quarry of Ytterby, in Sweden. This earth has since been met with only in one other mineral in the same country. Yttria (oxide of yttrium) is an insipid, white powder, which has no action on vegetable colours, and is remarkable for its specific gravity, which is 4.8. It is insoluble in water, and incapable of fusion, except at a very intense heat. With the acids it forms salts, having a sweetish, austere taste, but which have hitherto been but slightly examined. The metal has been procured, by decomposing the chloride of yttrium, by means of potassium, in the state of iron-grey scales, which burn brilliantly when heated in oxygen gas or common air, forming yttria. The metal is not acted on by water, but dissolves in sulphuric acids.

Thorinum.—Thorinum, or thorium, is the name given to a metal, discovered by Berzelius. In 1816, in analyzing some Swedish minerals, he obtained an earthy substance, which he concluded to be the oxide of a new metal (thorium), but he subsequently found it to be a subphosphate of yttria. However, in 1828, Berzelius received a black, heavy mineral from the vicinity of Brevig, in Norway; which, on analysis, was found to consist chiefly of a silicate of a new earth, which constituted about 58 per cent. of the whole mineral. To the base of this earth he gave the name of Thorium, because it resembled in its properties the subphosphate of yttria, to which the name had been previously applied. Thoria (oxide of thorium) displays considerable analogies with yttria, zirconia, and glucina.

Binary Combinations of the Metallic Elements of the Third Class with Oxygen and some other Non-metallic Elements.

Iron.

Black Oxide of I., 1 Ir. 1 Ox.
Red Oxide of I., 2 Ir. 3 Ox.
Chloride of I., 1 Ir. 1 Ch.
Perchloride of I., 2 Ir. 3 Ch.
Sulphuret of I., 1 Ir. 1 S.
Bisulphuret of I., 1 Ir. 2 S.

Nickel.

Oxide of N., 1 Nk. 1 Ox.
Peroxide of N., 2 Nk., 3 Ox.
Sulphuret of N., 1 Nk. 1 S.

Zinc.

White Oxide of Z., 1 Zn. 1 Ox.
Chloride of Z., 1 Zn. 1 Ch.
Sulphuret of Z. (Blende), 1 Zn. 1 S.

Cadmium.

Oxide of C., 1 Cad. 1 Ox.
Sulphuret of C., 1 Cad. 1 S.

Cerium.

Oxide of C., 1 Cer. 1 Ox.
Peroxide of C., 2 Cer. 3 Ox.

Lead.

Protoxide of L., 1 Ld. 1 Ox.
Red Oxide of L. (Minium), 2 Ld. 3 Ox.
Brown Oxide of L., 1 Ld. 2 Ox.

Lead *continued.*

Chloride of L., 1 Ld. 1 Ch.
Sulphuret of L. (Galena), 1 Ld. 1 S.

Copper.

Oxidule of C., 2 Cop. 1 Ox.
Oxide of C., 1 Cop. 1 Ox.
Deutoxide of C., 1 Cop. 2 Ox.
Chloride of C.
Perchloride of C.
Hemisulphuret of C., 2 Cop. 1 S.
Sulphuret of C., 1 Cop. 1 S.
Persulphurets of S. $\left\{\begin{array}{l}\text{1 Cop. 2 S.}\\ \text{1 Cop. 3 S.}\\ \text{1 Cop. 4 S.}\\ \text{1 Cop. 5 S.}\end{array}\right.$
Phosphuret of C., 1 Cop. 1 Ph.

Bismuth.

Oxide of B., 1 Bis. 1 Ox.
Chloride of B., 1 Bis. 1 Ch.
Sulphuret of B., 1 Bis. 1 S.

Mercury.

Black Oxide of M., 1 Mer. 1 Ox.
Red Oxide of M., 1 Mer. 2 Ox.
Chloride of M. (Calomel), 1 Mer. 1 Ch.
Perchloride of M. (Corrosive Sublimate), 1 Mer. 2 Ch.
Sulphuret of M. (Ethiops Mineral), 1 Mer. 1 S.
Bisulphuret of M. (Vermilion), 1 Mer. 2 S.

Silver.

Oxide of S., 1 Sil. 1 Ox.
Chloride of S. (*Luna Cornea*, Horn Silver), 1 Sil. 1 Ch.
Sulphuret of S., 1 Sil. 1 S.

Gold.

Oxide of G., 1 Gd. 1 Ox.
Peroxide of G., 1 Gd. 3 Ox.

Gold *continued.*

Chloride of G., 1 Gd. 1 Ch.
Perchloride of G., 1 Gd. 3 Ch.
Sulphuret of G., 1 Gd. 1 S.
Persulphuret of G., 1 Gd. 3 S.

Platina.

Oxide of P., 1 Pl. 1 Ox.
Deutoxide of P., 1 Pl. 2 Ox.
Chloride of P., 1 Pl. 1 Ch.
Bichloride of P., 1 Pl. 2 Ch.

Palladium.

Oxide of P., 1 Pal. 1 Ox.
Sulphuret of P., 1 Pal. 1 S.

Rhodium.

Oxide of R., 1 Rh. 1 Ox.
Peroxide of R., 2 Rh., 3 Ox.

Iridium.

$$\text{Oxides of I.}\begin{cases}\text{1 Irid. 1 Ox.}\\ \text{2 Irid. 3 Ox.}\\ \text{1 Irid. 2 Ox.}\\ \text{1 Irid. 3 Ox.}\end{cases}$$

Osmium.

$$\text{Oxides of O.}\begin{cases}\text{1 Os. 1 Ox.}\\ \text{2 Os. 3 Ox.}\\ \text{1 Os. 2 Ox.}\\ \text{1 Os. 3 Ox.}\\ \text{1 Os. 4 Ox.}\end{cases}$$

Iron.—But few of the elementary bodies with which we are acquainted occur so abundantly and in so many various forms as iron.

Among the metals, excepting some of the bases of earths and alkalies, there is not one which enters so largely into the composition of mineral, vegetable, and animal substances. It is also distinguished for its general utility, possessing admirable properties, adapting it for the construction of a multiplicity of weapons and instruments, useful in peace and war, in arts, manufactures, and for domestic purposes. Its capabilities were known, and to a certain extent, duly appreciated by the ancients; but they have been, in modern times, far more fully developed, and the metal and its compounds consequently rendered subservient in a most extraordinary degree to the luxuries as well as the wants of our contemporaries. Chain-bridges, steam-engines, watch-springs, and magnets, are among the numerous articles constructed of this metal, the invention of which is comparatively of modern date. Though iron when pure requires, to melt it, an extremely high temperature, it is susceptible of an imperfect kind of fusion at a white heat; for when exposed to that heat it becomes so much softened, especially at the surface, that if two pieces are placed in contact, and hammered, they may be most firmly and securely united. This operation is termed *welding*, and the temperature at which it is effected is sometimes called a *welding* heat. The combustibility of iron has been already noticed.* When it is burnt, either in oxygen gas or atmospheric air, the protoxide of iron is formed; if this compound be exposed to a red heat for some hours, it combines with an additional quantity of oxygen, and becomes converted into the peroxide. Both the oxides combine with water, constituting hydrated oxides of iron. Chloride of iron is a brittle, lamellar substance, of a grey colour, which requires for its fusion a red heat. Perchloride of iron is the product of the combustion of iron wire in chlorine gas. The metal burns with a red light, forming a compound which sublimes in iridescent brown scales. The bisulphuret of iron is a native mineral, occurring in the state of gold-coloured crystals, called pyrites. Iron combines in variable proportions with carbon: when the metal is in excess, composing the different kinds of steel and cast-iron; and when the carbon largely exceeds, forming plumbago.

Nickel.—This is a hard metal, of a white colour, malleable and ductile, but difficult of fusion, and not acted on by atmospheric air or water at common temperatures. When pure it may be rendered magnetic, like iron; and it has therefore been sometimes employed in the construction of magnetic needles. If exposed to intense heat with access of air, it becomes slowly oxidized; and it burns with vivid scintillations in oxygen gas.

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* See p. 73.

Zinc.—This metal in appearance resembles lead, but is when untarnished of a lighter colour. It speedily attracts oxygen when exposed to air and moisture; and it is easily dissolved by acids and alkalies, both in the metallic state and when oxidated. It is malleable and ductile when heated to between 210° and 300° Fahrenheit. At about 725° it melts, and becomes crystallized on cooling. If exposed to a temperature beyond its melting-point, with the access of air, it burns with a bright bluish flame, forming the oxide, formerly called flowers of zinc.

Cadmium resembles tin in its sensible properties; and when heated in atmospheric air forms a sublimate, which condenses into a brownish-yellow oxide. The oxides of this as well as the three preceding metals are readily reduced by heat alone to the metallic state.

Cerium.—The protoxide of cerium is a white powder, which differs from the oxides of the metals just described, in being extremely difficult of reduction. The metal itself is but imperfectly known.

Lead.—This is well known to be a heavy, soft, and readily fusible metal, which, though malleable and ductile, is deficient in tenacity. It soon becomes oxidized when exposed to a moist atmosphere. When heated by means of an oxyhydrogen blowpipe, it burns with a bluish flame. If melted and kept stirred, so as to promote the free access of air, it becomes converted into the protoxide, a yellow powder, used as a pigment under the name of massicot; and in a semi-vitrified state it constitutes litharge. The brown oxide of lead exhibits the phenomenon of spontaneous combustion, when it is triturated with sulphur. Lead in a finely-divided state, if thrown into chlorine gas moderately warmed, burns with a white flame, and throws off sparks. The product of this operation is chloride of lead, which may also be obtained by decomposing the solution of lead in nitric acid, by means of chloride of sodium (common salt). It fuses at a heat below redness, and when cooled again, has the appearance of a horny substance, whence it was formerly named horn lead (*plumbum corneum*).

Copper.—This metal being used for many domestic purposes, its physical properties are generally known. It is malleable and ductile beyond most other metals, except gold, silver, platina, and iron; hence it forms fine wire, and may be beaten into thin leaves. It burns brilliantly when heated in the combined flame of oxygen and hydrogen, giving out a dazzling green light. If exposed to air and moisture, it tarnishes, combining with oxygen to form a bluish-green rust (*ærugo*). The deutoxide or peroxide of copper is an insipid, black powder. Leaves or filings of copper take fire, and burn spontaneously in chlorine gas, forming the chloride of copper, a yellowish, slightly-transparent substance, easily fusible, which has been called resin of copper. If sulphur and filings of copper be heated together, a sudden and brilliant combustion takes place, even when the process is conducted in a vacuum.*

Bismuth.—This is a light reddish-coloured metal, of a lamellar structure, moderately hard, and destitute of malleability. It becomes tarnished by exposure to air; but is not affected by water. Its fusibility has been already noticed. If strongly heated in the air, it burns with a blue flame, forming a yellowish oxide, which has been called flowers of bismuth. This substance, like the oxide of lead, is fusible and vitrifiable. Finely-divided bismuth becomes inflamed when gently heated in chlorine gas, forming a grey, granular compound.

Mercury.—This metal is distinguished by its extraordinary fusibility, so that it requires a temperature 39° below zero, Fahrenheit, to congeal or render it solid. It is in that state malleable and ductile, though not to any great extent. It is extremely volatile, subliming in some degree at low temperatures; and at about 660° it boils rapidly, and may thus be purified by distillation, like water. When heated a little beyond the boiling point, it becomes oxidated; and if the oxide be exposed to a considerably higher temperature, the oxygen is driven off, and the metal revived.† The chlorides of mercury are among the most important preparations of this metal used in medicine. The first, commonly called calomel, may be formed by exposing the metal to chlorine gas at common temperatures; but the usual mode of obtaining this compound is by decomposing the solution of mercury in nitric acid, by means of muriatic acid or chloride of sodium (common salt). The product is a ponderous white powder, which when exposed to heat sublimes unaltered. The perchloride of mercury is a crystalline substance, which may be procured by heating the metal in chlorine gas; but it is prepared for use by boiling together sulphate of mercury and common salt. It is well known as a powerful poison. The bisulphuret of mercury, which occurs as a native mineral, under the name of cinnabar, and the same substance artificially produced, affords a fine scarlet colour for painting.

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* See p. 29.

† See p. 33.

Silver.—This metal requires a great heat to melt it; but by a fierce and long-continued fire it may be volatilized. It does not tarnish in the air from absorption of oxygen; but, when sulphurous vapours are present, its surface becomes tinged with purple from the formation of sulphuret of silver; and the same effect is produced when a silver spoon is dipped in the yolk of an egg, which contains sulphur. The oxide of silver may be formed by exposing the metal to intense heat, with the access of air; but it is more readily obtained by decomposing the nitrate of silver with lime-water, when it constitutes a tasteless, olive-coloured powder, insoluble in water. Chloride of silver has the same horny appearance as chloride of lead; and it is therefore called horn silver (*luna cornea*).

Gold.—The most powerful heat of our furnaces has no effect on this metal beyond that of fusing it; but it may be made to undergo combustion, and form a purple oxide, by heating it with the flame of an oxyhydrogen blowpipe, or by means of electricity. It may also be oxidated indirectly by solution in the nitro-muriatic acid (*aqua regia*), and precipitation by caustic potash or magnesia. If the peroxide of gold be dissolved in muriatic acid, and ammonia be employed to precipitate it, a detonating powder (*Aurum Fulminans*) will be obtained, which explodes when rubbed or heated.

Platina.—This metal in a state of purity is the heaviest body hitherto discovered, having nearly 22 times the specific gravity of water. It is so difficult of fusion, that it can only be prepared for use by a complicated process. But, like iron, it may be welded by hammering the metal when intensely heated; and thus vessels and other utensils may be formed, highly valuable for the purposes of art, on account of their relative indestructibility. Platina may be oxidated by treating it with nitro-muriatic acid and alkali, as in the case of gold, or by heating it with nitre, and likewise by the influence of electricity.

Palladium, *Rhodium*, *Iridium*, and *Osmium*, are metals which have been found in comparatively small quantities, mixed with crude platina, in the state in which it is brought from abroad. Palladium forms a hard, durable alloy with gold, which has been used in the construction of mathematical instruments: and rhodium has been employed for pointing the nibs of pens. Iridium and osmium do not appear to have been applied to any useful purpose; nor do the compounds of either of these four metals require to be further noticed.

The preceding notices of the elementary bodies, non-metallic and metallic, and of their most important primary compounds, are chiefly intended to serve as an introduction to the study of the subjects discussed in the ensuing treatises. There are several interesting topics of chemical science, as the formation of the acids and alkalies with composite bases; of the neutral salts, oils, and soaps; the nature of the products of vinous, acetous, and putrefactive fermentation, and especially of alcohol and others; besides various other points, which have been very slightly, or not at all noticed, as being incompatible with the limited extent of this work. For further information concerning these and other subjects, the reader may be referred to the Treatises on Chemistry, by Thomson, Henry, Brande, and Turner; or to the more extensive work of Berzelius, a French translation of which has been recently published.

METALLURGY.

LA METALLURGIE PROPREMENT DITE EST L'ART DE PURIFIER LES MINERAIS ET D'EN OBTENIR LES METAUX AU DEGREE DE PURETE QU'EXIGENT LES DIFFERENS ARTS. L'ON A SOUVENT ETENDU L'ACCEPTION DE CE NOM A TOUTES LES OPERATIONS QUI SE PRATIQUENT EN GRAND SUR LES MINERAIS POUR EN RETIRER DE COMBUSTIBLES, DES SELS, &C.; MAIS CES OPERATIONS APARTIENNENT A LA MINERALLURGIE. LA METALLURGIE EST UNE DES APPLICATIONS LES PLUS IMPORTANTES DE LA CHIMIE; C'EST DE LA DOCIMASIE EN GRAND: MAIS IL Y A CETTE DIFFERENCE NOTABLE QUE DANS LA DOCIMASIE ON NE S'ATTACHE QU'A BIEN CONNAITRE LA QUANTITE DE METAL ET LES CORPS ETRANGERS QUI CONSTITUAIENT LE MINERAI SANS S'EMBARRASSER DES FRAIS D'OPERATION, QUI, E GENERAL, SONT PEU CONSIDERABLES A CAUSE DE LA PETITE PORTION DE MATIER SOUMISE A L'ANALYSE; TANDIS QU'EN METALLURGIE ON A EN VUE DE CONNAIT ET DE RETIRER LE METAL, ET SURTOUT D'OPERER AVEC LE PLUS D'ECONOMI POSSIBLE.

*Métallurgie Pratique, par MM. D * * * * et L * * *, Paris,* 1827, *Introd.*

METALLURGY.

The term Metallurgy, in its most extensive signification, denotes the working of metals,[*] and may thus include all operations connected with the raising of metallic ores from mines, or procuring them from metalliferous sands; those employed for ascertaining the value of minerals whence metals are obtained; the multifarious processes relative to the extraction of the various metals from their respective ores; and the still more numerous processes which relate to manufactures of hardware, steel, tin-plate, brass, bronze, gold and silver plate, as well as of other metals and their combinations. But Metallurgy in a more restricted sense, is to be regarded as a department of Chemistry, comprising the description and rationale of those chemical operations by means of which the useful metals and their alloys are separated from the saline, earthy, or stony substances in conjunction with which they are presented to us by nature. Under this point of view the subject will be treated in the following pages; but some preliminary notices of metallic veins, mines, and the art of mining, may be introduced, as being both interesting and instructive, tending to illustrate the properties and composition of those substances to which the attention of the metallurgist or metallurgic chemist is principally directed. Docimastics, or the art of Assaying, as a process preceding the reduction of metals, will also demand our attention.

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[*] From the Greek Μέταλλον, *metal*, and Εργον, *work*.

MINERAL DEPOSITS AND MINES.

Nature presents metallic substances to our notice scattered on the surface or inclosed within the crust of the terrestrial globe, either in a state of purity, or in combination with various other bodies. These combinations are properly termed mineralized metals, or ores; metals in this state being united to extraneous matter, which alters their properties in such a manner, that their real nature can only be ascertained by chemical analysis. Sometimes two or more metals are combined with the same mineralizing body; frequently a single metal is united with several such bodies, and yet more frequently, in mines, are found combinations consisting of several metals and various mineralizing bodies united together. A few only of the metals (almost exclusively those which are termed precious metals) are found in a state of purity dispersed through the soil of valleys, or mixed with the sand of rivers, or with earthy matter deposited by mountain torrents. It is thus that gold and platina, and especially the former, frequently occur in masses, often minute, sometimes of several pounds weight, and of all intermediate sizes, in alluvial soil, from which the metal is separated principally by mechanical means. Both metallic ores and native metals are occasionally disseminated in grains through rocks, and when they are thus found in abundance, the whole mass of the rock is worked as a mine; but this is comparatively seldom the case. Tinstone, or the oxide of tin, is sometimes thus dispersed through the substance of granitic rocks in Cornwall, but this is generally observed in the vicinity of veins of tin ore. This metal is likewise found in alluvial soil, in small nodular masses, of considerable specific gravity, called stream-tin from the manner in which it is procured, by washing the metalliferous sand.

Mineral deposits, however, more usually occur in subterraneous beds, or veins. Metallic ores of some kinds form regular strata, or mineral beds, in secondary rocks, or in the more ancient transition and primary rocks. These beds are in general horizontal, but they are sometimes observed to be highly inclined, and such strata have been mistaken for veins. The ores of copper, iron, and lead, are occasionally found in conjunction in beds in primitive mountains, sometimes having gold or silver intermixed with them. Cobalt, and certain ores of mercury, likewise form strata. Iron ore is frequently found in beds of great thickness, interposed among rocks of gneiss, mica-slate, and clay-slate. Lead, zinc, manganese, and iron ores also occur abundantly in strata in secondary mountains. When a bed of metallic ore expands irregularly, it sometimes forms masses of such magnitude as to resemble small mountains, as is the case with iron ore in Sweden and Norway. Metallic beds, however, are generally of limited extent, seldom traversing an entire mountain, but gradually or suddenly terminating in a thin edge; in the language of the miners, a stratum of ore is said to *wedge out*. Beds of minerals are not of frequent occurrence in England, most of the great deposits of metallic matter in this country being found in veins, as is uniformly the case in the great mining district of Cornwall, except in the previously noted stream-works. Mr. Bakewell, however, alleges that beds of copper pyrites have been wrought in transition rocks in Cumberland, and that the existence of mineral beds may be suspected in other counties, where they are often confounded with veins by the labouring miners.

Mineral veins, from their relative frequency, constitute the most considerable depositories of metallic matter. Such veins are not, as might be supposed from the general application of the term, tubes filled with metal or ore, but extended plates, or laminæ, of unequal thickness; and they differ most essentially from beds, in that they do not run parallel with the direction of other strata, but traverse or cross them vertically, or at various degrees of inclination. A vein may be described as a fissure in a rock, filled with various substances. Humboldt noticed a vein of calcareous spar 140 feet in thickness, traversing gneiss, in the Alps of Switzerland; and Professor Jameson mentions a vein of porphyry slate, nearly 160 feet wide, occurring in sandstone, in the Isle of Arran; and veins of pitchstone and greenstone, varying in width from ten to one hundred feet. But these do not appear to have been of the nature of metalliferous veins, which are commonly much narrower; yet it is said, that in the silver-mines of Pasco, in Peru, there is a vein of brown ironstone, containing silver, which is 1300 yards in width.

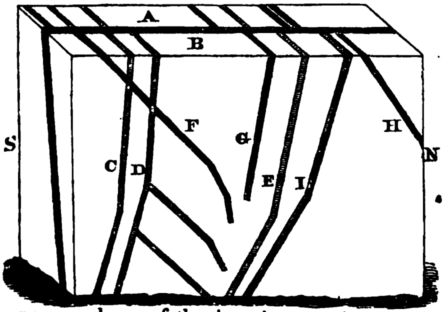
When metallic ores are worked in beds, or in veins of considerable thickness, that part of the rock which covers the ore is called the roof, and that which supports it the floor. These terms, however, are principally applicable to mines worked in an horizontal direction. The metalliferous veins of Cornwall which are of most importance, namely, those producing tin and copper, extend nearly in the direction of east and west, with little variation. Though there are other veins, either destitute of metallic matter, or else containing lead and silver, which chiefly run north and south. The veins of Cornwall scarcely ever descend vertically, or exactly at right angles with the horizon, but almost always dip from the line of descent; and this deviation from the perpendicular is called by miners the *hading* of the vein; thus a vein may be said *to hade* or dip to the north or south. Metalliferous veins in general seem to observe no great uniformity of direction, some descending *almost* perpendicularly, and others very obliquely, in such a manner that in a single hill instances may be observed in which veins of different descriptions dip or underlie in almost all directions, traversing each other in such a manner as to defy the calculations of the miner. The head of a vein sometimes rises to the surface of the soil, and may thus be discovered; and its existence is occasionally betrayed by a certain ochraceous or rust-like appearance, which may be observed above its site, but this is not very common. To what depth metallic veins may descend, has never been ascertained, for no instance has yet occurred of the termination of a vein being reached, though sometimes veins are found to become so thin and unproductive, as not to repay the labour of working deeper; but more frequently the progress of the miner is stopped by water or other obstacles. Some of the Cornish mines are said to be nearly 500 yards in depth from the surface, as the copper and tin mine of Dolcoath, which is 456 yards deep; and there are several the depth of which is from 300 to 400 yards. The same vein sometimes contains different ores at different depths: thus the ores of iron, copper, cobalt, and silver, are found successively in some of the mines in Saxony; and in France there are mines containing iron ore, below that silver ore, and in the lowest part copper ore. In

Cornwall sulphuret of zinc, or blende, is found abundantly in the upper part of veins, which lower down are rich in copper, and sometimes tin in the same manner occurs in the superior part of a copper vein. The thickness of veins, as already observed, is extremely variable, the same vein may be in some parts but a few inches wide, and in others extend to the thickness of many feet, or even yards. The vein at Dolcoath mine varies from two feet to forty; and in some places is contracted to about six inches. The veins, independent of their extent may be characterized as rich or poor. In a Cornish mine called Whealan Cotes, was found a vein of tin ore but three inches wide, yet so rich as to be worth working. Some of the veins containing copper, in Herland mine, did not exceed six inches in width, and after thus continuing for a few fathoms, they passed away east and west into mere strings, or rather laminæ, scarcely thicker than paper; but these veins yielded ore of a rich quality. The thin veins or threads of metallic matter which sometimes occur in working mines may be worth pursuing, independent of their product of metal, as they may lead to veins of much greater thickness, or to bunches, or large masses of metal.

Veins are by no means entirely filled with metalliferous matter, which in fact occupies comparatively but a small space, the veins including minerals of different descriptions. The non-metalliferous parts of a vein, of whatever nature they may be, are usually termed by the miner *deads*, as being unproductive and useless. Large empty spaces occasionally occur in veins, but this is not often the case in the mines of Cornwall. Water is found in large quantities in mines, especially those which are rich in tin or copper. The sides of metalliferous veins are usually very determinate, being covered by a hard, dark-coloured incrustation, called by the miner the walls of the vein: and there likewise commonly runs down every vein a small seam of whitish clayey matter, sometimes adhering to one side of the vein, and sometimes to the other. The same substance which constitutes the incrustation of the veins, is also often intermixed with the ore, forming with it alternating layers, and with other substances composing what is called the matrix, gangue, or veinstone of the mineral. Different metals are accompanied by different kinds of gangue, the nature of which may enable the miner to form a judgment as to the probable value of the vein. Among the substances thus found may be mentioned quartz, calcareous spar, fluor spar, called in Derbyshire blue john, and sulphate of barytes, also called cawk; besides which, the ores of one metal are thus accompanied by those of another, and frequently by pyrites (sulphuret of iron).

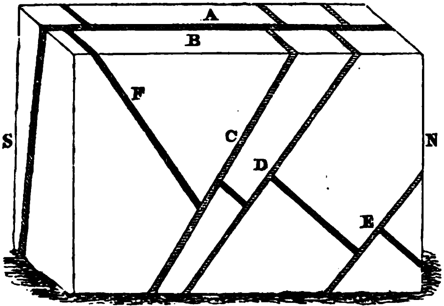
It has been already stated that in Cornwall tin and copper mines uniformly run in the direction of east and west, and that other veins extending north and south scarcely ever contain a trace of either of those metals, being non-metalliferous, or else affording the ores of silver, lead, cobalt, or iron, or occasionally antimony. These north and south veins are most commonly filled by quartz, by a whitish or bluish argillaceous substance, or by a kind of ochre, and sometimes by all three. When such a vein meets with another containing tin or copper, it passes through the tin or copper vein without interruption, while the latter becomes split, or frittered into numerous small branches, and sometimes its contents seem to be dissipated, so that the miner loses all traces of the vein, or only recovers it after a tedious search at the distance of perhaps between 400 and 500 feet. North and south veins differ greatly in breadth, but whatever be their dimensions, they always divide the tin or copper veins which they encounter, and generally alter the direction of the latter, or, in the language of the miner, *heave* them out of their course.

The manner in which metalliferous veins are sometimes interrupted by others, may be illustrated by the following section of the mine of Tincroft, in Cornwall:



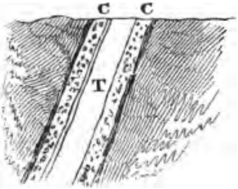
A B represents the surface of the mine, with a vein running from north to south, and crossed by tin and copper veins from east to west. The veins, C,D,E, are veins of copper, F, G, H, veins of tin, and I, a vein yielding both tin and copper. Two of the opper, and one of the tin veins, running east and west, are intersected by the non-metalliferous north and south veins, by which they are heaved out of their regular course towards the south. It may also be perceived that one of the tin veins, F, is intersected by two of the copper veins, C and D, which pass through it without affecting its direction.

The manner in which copper veins intersect those of tin, always passing through them, and generally heaving them from their course, may be understood from the following section of the Pink mine.



A B may be supposed to represent the surface, along which runs a vein from north to south, intersecting metalliferous veins passing from east to west. The veins C, D, E, are copper veins, and F a vein of tin; and here it will be seen how three of these veins have their western sides heaved towards the north, by the non-metalliferous vein passing through them. The tin vein running near the southern extremity of the mine underlies greatly towards the north, while the copper veins, on the contrary, underlie towards the south. One of the latter veins, C, meeting the tin vein, F, in its course, interrupted it, and heaved that part of it northward of the point of intersection twenty-four fathoms nearer to the surface, and the same tin vein was interrupted by another copper vein, D, and heaved about ten fathoms towards the surface; a third time it was cut through by another copper vein, E, not shown on the surface, and again heaved somewhat out of its course.

Sometimes one vein crosses another without causing any change of direction, and if both have nearly the same inclination, they are usually richer near their junction. Where two veins in the same district have the same direction, or run parallel, it has been observed that their contents are similar, but where they run in contrary directions, their contents are dissimilar. Molina, in his History of Chili, gives an account of a vein of silver at Uspalata, in the Andes, which is nine feet in thickness throughout its extent, having been traced ninety miles; and it has smaller veins branching off on either side, and penetrating the adjacent mountains to the distance of thirty miles. It has been conjectured that this vein reaches 300 miles. In Northumberland and Durham cross courses have been found to contain ore near their junction with strong veins. In Cornwall, at Botallac mine, near the Land's End, a cross course running north and south, is enriched by the junction of east veins, which have been compared to small rivulets opening into a river. The cross course is rich in ore to the extent of twenty or thirty fathoms on either side of its junction with a vein, but no veins are found branching from the west side of the cross course. The vein contains grey copper ore of a fine quality. Sometimes a vein contains tin ore in the centre, surrounded laterally by copper ore, as represented in the marginal figure.



In this vertical section of a part of the vein, T denotes the central portion, consisting of tin, and C, C, the copper ore on each side of it.*

The different metals are found respectively in different parts of the world, in various situations, and associated with peculiar kinds of rocks, stones, sand, or alluvial soil.

Gold is found in America, in Mexico, N. Carolina, Brasil. New Granada, Chili, Peru, and Buenos Ayres; in Africa, in Kordofan, Bambouk, and on the eastern coast opposite the island of Madagascar, and especially in Sofala, supposed to be the country of Ophir, mentioned by the Jewish writers; in Asia, in Thibet, Japan, Formosa, Ceylon, Java, Sumatra, Borneo, the Philippines, and other islands of the Indian Archipelago, in Siberia, in the Ural and Altai Mountains, between the rivers Obi and Irtisch; in Europe, in Hungary, Transylvania, the country round

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* Bakewell's Introd. to Geology, 4th ed. p. 427.

Salzburg, and the Hartz Mountains, in Piedmont, in Spain, chiefly in the Asturias, and the Pyrenees, in France, in rivers occasionally in small quantities, and formerly in Thrace, Macedonia, and some of the Greek islands. Gold occurs in primary and transition rocks, in porphyry and syenite, and in the lowest sandstone; it has been occasionally found in coal, and sometimes in volcanic rocks, and most abundantly in the sands of rivers, or in that mixture of alluvial matter called cascalhao, consisting of pebbles, gravel, and minute particles of siliceous and argillaceous earths, and oxide of iron. It is usually in the state of grains, minute scales, or pellets of various sizes, and it is thus collected by the African negroes, and brought for sale in ostrich and vulture quills. Sometimes it is met with in large masses; in 1730, a block was discovered in Peru, weighing forty-five pounds; and about 1810, gold was obtained from several rivers in North Carolina, one mass weighing twenty-eight pounds. This metal is sometimes disseminated in threads or in laminæ alloyed with tellurium and silver, and it is likewise mixed with the sulphurets of iron, of silver, of copper, of arsenic, of mercury, and other metals.

Platina was first discovered in the provinces of Choco and Bogota, in South America, and it has since been found in the province of Barbacoas, near the shores of the South Sea; in Brazil, in the island of St. Domingo, in North America, in very minute quantities in ores of argentiferous grey copper at Guadalcanal and Casalla, in Spain; and recently in greater abundance on the western or European side of the Ural mountains, in the territories of Russia. It occurs generally in the sands of rivers, intermixed with palladium, rhodium, osmium, iridium, and other metals.

Silver is found in America, in Mexico, Peru, Chili, and Buenos Ayres; in Asia, in China, Thibet, and Siberia; in Europe, in Norway, Sweden, Hungary, Saxony, Transylvania, Moravia, Austria, Bohemia, the Tyrol, Hanover, Brunswick, Prussia, the Netherlands, France, Savoy, and Great Britain; but in the latter only as a subordinate product of lead or copper ores. It occurs principally in veins in primitive rocks, and in some transition and secondary rocks.

Lead is found in America, in Mexico, Brazil, and the North American United States, Louisiana, and Virginia; in the Russian empire in the environs of Nertschinsk on the frontiers of Chinese Tartary, and in Armenia; in Europe, in France, Savoy, the Netherlands, the

Prussian States, the Hartz Mountains, in Saxony; in the Austrian dominions, and other parts of Germany; in England, especially in Derbyshire and Lancashire; in Scotland, in Ireland, and in Spain. Galena, which is the most common ore of lead, occurs in primitive as well as secondary rocks, and in this country the richest mines are in slate and limestone. Lead ores are found generally in the older rocks, except trapp and serpentine; in porphyry and syenite, in the lowest sandstone, and occasionally in strata of coal.

Copper is found in Europe, in France, Germany, Transylvania, Silesia, Sweden, Norway, Great Britain, Ireland, and Spain; in Asia, in Siberia, Kamtschatka, Japan, China, Persia, Arabia, and the Indian Islands; in Africa, in Barbary, Morocco, Abyssinia, in the mountains north of the Cape of Good Hope, and in the Namaqua country; in America, in Mexico, Chili, and Brazil, in which last country a mass was discovered weighing 2666 Portuguese pounds. It occurs in primitive and transition rocks, porphyry, syenite, and sometimes in sandstone, in coal strata, and alluvial soil.

Tin is found in England more abundantly than in most other countries, mines or tin-works of some kind having existed in Britain before it was known to the Romans, and it was imported from this island by the mariners of Phenicia and Carthage. The other parts of Europe in which it principally occurs, are Saxony, Bohemia, and France; the quantity found in Spain and Portugal is inconsiderable. In Asia it is found in China, Siam, Pegu, in Sumatra, Ceylon, Banca, and other islands; and in America, in Mexico, and Buenos Ayres. It is considered as one of the most ancient of metals, having been discovered only in primitive rocks, as granite, gneiss, mica-slate, and clay-slate, or disseminated in soils formed from the decomposition of such rocks.

Mercury is found in Europe, in France, Bavaria, the Austrian dominions, and Spain, and in Italy and Sicily, but in comparatively small quantities; in Asia the most productive mines are in China and Japan; and in America, in Mexico and Peru, especially that of Guancavelica. Mercury differs from the metal just noticed, occurring but rarely and in small quantities in primitive countries, the principal deposits being found in bituminous slate, shell-limestone, and breccias. Dolomieu discovered it among the products of volcanoes, doubtless sublimed by subterranean fires.

Iron is the most abundant of metals in every part of the world, and is found in Europe, in England, Scotland, in Ireland more rarely, in France, Sweden, Norway, the Austrian Empire, in the southern part of Russia, in Bavaria, Prussia, Saxony, Hesse, the Netherlands, Switzerland, Savoy, Piedmont, Naples,* Sardinia, Elba, Spain, and Portugal; in Asia, in Siberia, Armenia, Natolia, Persia, Arabia, Tartary, Indostan, and China; in Africa, in Morocco, and in Congo; and in America, abundantly in several of the United States, in Mexico, and Brazil. This metal is so generally diffused throughout the mineral kingdom, that, as Mr. Brande observes, "there are comparatively few fossils which can be said to be perfectly free from it." There is no kind of rock or formation—primitive, transition, secondary, alluvial, or volcanic, in which it does not make its appearance; and its saline combinations, being dissolved in subterraneous waters, form chalybeate springs.

The principal mines of *Antimony*, in Europe, are those of Scotland, Hungary, Bohemia, Saxony, France, Spain, Transylvania, and at Neuwied, below Coblentz, on the right bank of the Rhine; and in America, in Mexico, and Brazil. It occurs in primitive and transition rocks, exclusive of trapp and serpentine; and likewise in porphyry and syenite.

Bismuth is obtained in England, France, Germany, and Sweden; in Siberia, and in Brazil; chiefly from mines of other metals. It appears to belong exclusively to primitive countries.

Zinc is found in Belgium, in the territory of Limburg, in Prussia, Austria, France, Spain, and England; in Siberia, where the mines are not worked; and in America. It occurs in primitive, transition, and secondary rocks, calcareous, argillaceous, and siliceous.

Cobalt is found in Saxony, Austria, Prussia, Hesse, and other parts of Germany, Norway, and Sweden; likewise in France and Spain, but the mines are not worked. It occurs in primitive mountains, except those of limestone, trapp, and serpentine; and likewise in transition mountains, and in sandstone.

Nickel is found in France, Spain, Bohemia, and in England more rarely; likewise in Siberia: and it is a general, if not a constant component part of aërolites. This metal, which is one of the least abundant, is usually met with in the same situations with cobalt and arsenic, accompanying the ores of those metallic bodies.

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* Oxidulated iron is said to have been collected on the sea-shore, near Puzzuoli.

Manganese is among the products of the mines of England, Scotland, France, Hungary, Transylvania, Saxony, and Bohemia. It is found in primitive and transition mountains, and sometimes in the lower stratified rocks.

Chrome occurs in France, Norway, the Tyrol, and at Ekatherineberg, in the Ural Mountains. It is generally embedded in gneiss or mica slate.

Arsenic is found in Saxony, Silesia, Baden, Hungary, and Transylvania; and in England, in Cornwall; in Siberia, in Armenia, on the right bank of the Euphrates, and elsewhere; in the tin-mine of Kianfu, in China; and in Mexico. It occurs in primitive and transition mountains, and in porphyry.*

The other metals have scarcely yet been applied to any purposes of utility; and most of them are of rare occurrence.

ART OF MINING.

The working of mines for the purpose of extracting metallic ores, may be supposed, like several other useful arts, to have originated from accidental circumstances. It has been already stated, that some metals, and especially gold and silver, have been occasiónally found on the surface of the earth, or at an inconsiderable depth beneath it; and hence it may not unreasonably be presumed, mankind first became acquainted with the treasures of the mineral kingdom of nature. But though accident might have led to the discovery of the precious metals, which always occur in a state of purity, or else mechanically mixed with other substances, that is by no means the case with metals in general, by far the greater number being obtained in the form of ores, consisting of sulphurets, oxides, chlorides, or metallic salts, constituting chemical compounds, often presenting to the inexperienced eye no traces whatever of the usual characteristics of a metallic body. If, therefore, such had been commonly dispersed on the superficies of the terrestrial globe, they might for ages have passed unnoticed or unappropriated, till their real nature and composition had been developed by some fortunate accident, or ascertained by the slow process of observation and experiment. Some have ascribed the discovery of the nature of metallic ores, and of the method of reducing them, to the conflagration of forests on the sides of metalliferous mountains. Bishop Watson says, "The most obvious method of clearing a country of its wood is setting it on fire; now in most mineral countries there are veins of metallic ores, which lie contiguous to the surface of the earth, and these having been fused whilst the woods growing over them were on fire, probably suggested to many nations the first idea of smelting ores:

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* Nouv. Dict. d'Hist. Natur. appliquée aux Arts, &c. Paris, tom. xxi. 1818: Art. Mine; Bakewell's Introd. to Geology, chap. xix.; and Métallurgie Pratique, formant partie de la Bibliothéque Industrielle. Paris, 1827.

> ——— 'Powerful gold first raised his head,
> And brass and silver, and ignoble lead:
> When shady woods on lofty mountains grown,
> Felt scorching fires; whether from thunder thrown,
> Or else by man's design the flames arose—
> Whatever 't was that gave these flames their birth,
> Which burnt the tow'ring trees and scorched the earth;
> Hot streams of silver, gold, and lead, and brass,
> As nature gave a hollow, proper place,
> Descended down and formed a glitt'ring mass.'

"There is no natural absurdity in this notion of the poet; and indeed it is confirmed by the testimony of various ancient historians, who speak of silver and other metals being melted out of the earth during the burning of the woods upon the Alps and the Pyrenees. A similar circumstance is said to have happened in Croatia, in the year 1762: a large mass of mixed metal, composed of copper, iron, tin, and silver, having been fluxed during the conflagration of a wood which was accidentally set on fire."*

The discovery of the existence of veins of metallic ores within the bowels of the earth, whether it originated solely from researches undertaken in consequence of such fortuitous circumstances as those here specified, or from some other causes, must have led to some of the simpler processes of mining; and the art must have been improved and extended, like other arts, by the invention of methods for overcoming occasional obstacles, and through the necessity that from time to time occurred of making experimental researches. In the prosecution of such undertakings the miner must frequently be guided by appearances, on which he may perhaps be induced to rely, without being at all able to trace their connexion with the objects of which he is in quest. "Thus a green, earthy matter is a good symptom in a tin-mine; a brown, ochry earth, and compact iron pyrites, are regarded as favourable omens in a copper-mine. Detached pebbles of ore, or fragments of veinstones, have sometimes led to the riches of the vein; and tin has especially been thus discovered in Cornwall. The miners, though a shrewd class of people, are often preyed upon by the most vulgar superstition, and many ancient absurdities are still retained and cherished in their art. The divining-rod and other oracles are yet consulted; genii are said to preside over the mines; and he who inadvertently whistles when below ground, breaks the spirits of his companions for the day, though freely permitted to indulge his musical disposition in the form of a song.

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* Chemical Essays, vol. v.

"In older mineralogical works, we read much upon these and other subjects. Flames of light have been described as playing over a district which afterwards has been found to contain subterranean riches; and this may have arisen from the good electrical conducting powers of the vein. The waters issuing from the soil sometimes hold metallic salts in solution, and repositories of metals have been discovered by circumstances of this kind. Copper veins tinge waters blue, and a piece of grease put into them becomes rapidly stained of that colour. There is no popular notion more common than that metals grow in the veins; an idea which may very probably have originated from observing the depositions of one metal by the introduction of another into its solution, as when silver is precipitated by the introduction of a plate of copper into its solution, or copper by iron.

"Districts rich in metals are generally barren, and seem peculiarly dreary and desolate to the traveller. This partly arises from the nature of the strata, and partly from the heaps of rubbish and hills of stone thrown upon the surface, and partly from the operations carrying on in the vicinity being inimical to vegetation. The high road through Cornwall, especially near Redruth, is an excellent specimen of this kind of country; while, at the same time, the romantic beauty and luxuriant vegetation of many parts of that county and of Devonshire, prove that exterior cultivation is not always incompatible with internal riches. The neighbourhood of the Parys mountain, in Anglesea, is singularly marked by sterility and gloominess. The soil, naturally unproductive, is rendered more so by the poisonous waters that traverse it, and by the sulphurous vapours that float around. There are not only no shrubs and trees, but the barrenness is unrelieved even by a single blade of grass, or the rusty green of a hardy lichen."*

The construction of works in mines must vary according to circumstances, as the forms of hills, the position of ores in beds or veins, and the obstacles to be encountered in excavating them. Sometimes mines are formed by driving a level from the mountain to reach the vein, the contents of which may be removed through this lateral opening; in which case shafts are only required for ventilation. This seems to be among the simplest modes of operation; and another is, following the ore from its outlet at the surface as far as circumstances will allow. When regular metallic veins are found in primitive rocks they are sometimes worked to great depths, by more varied and extensive operations, being occasionally carried below the level of the sea. In such cases perpendicular shafts are formed, by means of which the accumulating water is drained by machinery; and these shafts communicate with levels driven upon the lode or vein at various depths.

The art of mining comprises a variety of processes, essential or accessary, the most important of which are included in the following enumeration: 1. Works of research, undertaken for the purpose of discovering metallic beds or veins. 2. The construction of shafts and galleries. 3. The tracing of the bearing, direction, and probable extent of the mineral deposits. 4. Excavating the metallic ores. 5. Works requisite for ensuring the security of the shafts and galleries; as propping, planking, plastering, walling, building arches, &c. 6. Making air-shafts or funnels, and other arrangements necessary for securing a proper ventilation throughout the works. 7. Methods of raising or transporting ores or minerals to the surface. In the mines of England and Silesia, iron railroads or canals are sometimes constructed for the conveyance of the mineral produce; as in the Worsley coal-mines, in Lancashire, where subterranean canals were formed by the cele-

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[*] Brande's Lectures on Geology, lect. vi.

brated Brindley, before the middle of the last century. In the iron-mines at Fahlun, in Sweden, and in the mines of rock-salt, in Galitzia, and elsewhere, when the excavations are sufficiently capacious, horses are sometimes introduced to work underground, a practice which does not appear to have been adopted in England; though those animals were commonly employed to work machinery on the surface, before the introduction of steam-engines into the mining districts, and are still of course in many situations. 8. Removing or stopping out water. 9. The accessary operations of blasting rocks with gunpowder, or firing them by kindling on their surfaces large piles of wood, and thus causing them to split by the effect of heat, as is practised in the mines of Rammelsberg, in the Hartz; those of Geyer and Altenberg, in Saxony; of Felsobanya, in Transylvania; of Kongsberg, in Norway, and others. 10. Among the most important accessary arrangements are those which relate to lighting the mines, and providing against the danger of explosion where the inflammable vapour called fire-damp occurs; and to obviate this various plans have been adopted, as the use of steel-mills, and Davy's wire-gauze lamps.*

Any detailed notice of mining operations, though it might be rendered interesting, would be quite inconsistent with the plan of this work; but a few particulars may be added, relative to the manner in which gold and silver mines were worked, both in Europe and America, in the seventeenth century; and also concerning the modes of proceeding at present among the Cornish miners in our own country.

At Kremnitz, in Hungary, there is a gold mine, which when it was visited by Dr. Browne, about 1680, had been worked nine hundred and fifty years. It was nine or ten English miles in length, having one horizontal passage or gallery, eight hundred fathoms in length, called the Erbstall. Its depth was above one hundred and seventy fathoms. Ladders were not used to descend into the mine, but persons were let down by a cable, to which was affixed a seat of leather, affording a safe and convenient carriage even to those who were not used to it. There were six shafts or perpendicular pits that might be entered in this manner, each having a distinct name: 1. That of Rodolphus

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* See Book of Science, pt. i. p. 335; 2d edit. p. 341.

2. Queen Anne. 3. Ferdinand. 4. Matthias. 5. Windshaft. 6. Leopold. "I went down," says the traveller, "by the pit of the Emperor Rodolphus, gently descending by the turning about of a large wheel, to which the cable is fastened, one hundred and eight fathoms deep into the earth; and after many hours being in the mine, was drawn out again by Leopold's pit, strait up above one hundred and fifty fathoms, a height surpassing that of the pyramids by a third part. At the bottom of which pit I was not discouraged to find myself so deep in the earth, for considering I was yet above three thousand miles from the centre,* I thought myself but in a well. It is built on all sides with fir-trees, one lying upon another (like transverse logs), on the four sides, from the top to the bottom. The miners work towards one, two, or three of the clock, as they speak; for they direct themselves under ground by a compass, not of thirty-two points (such as is used at sea), but by one of twenty-four, which they divide as we do the hours of the day, into twice twelve."†

The silver-mines of Potosi, in Peru, which are among the richest hitherto known, were discovered in 1545. For the more convenient working of the mines, the Spaniards dug galleries, which they call Socabonos, from the foot of the mountain of Potosi, towards the west, passing through horizontally to the mine, each gallery being eight feet broad and a fathom deep, and closed with gates that might be locked, through which the silver is carried out, and where the owner of the socabon receives a fifth part. The socabon leading to the rich vein was begun in 1556, and finished in twenty-nine years, extending two hundred and fifty rods in length. The miners work by candlelight, both day and night, by turns: those that work in the day sleeping in the night, and those that work in the night sleeping in the day. The ore, which is as hard as a stone, is cut out with pickaxes, beaten in pieces with an iron crow, and carried by the miners, upon their backs, up ladders made of leather. Each ladder has three leathern ropes, about the thickness of a cable, stretched out by sticks, so that one labourer may go up on one side, while another comes down on the other. Each ladder being ten fathoms in length, has its respective floor, on which the labourers rest during their ascent; the number of the floors differing according to the depth of the mine. The men carry the ore in bags fastened before their breasts, and passing over their shoulders behind their backs; going up three and three together, the foremost with a lighted candle tied.to his thumb, so that both hands are at liberty. Thus loaded they scramble up and down one hundred and fifty fathoms; exposed, besides other perils, to the danger of destruction from the falling in of the mines, or of part of the sides of the ill-constructed pits or shafts. They suffer also from the cold temperature of these subterranean passages. The silver runs for the most part between two rocks, as in a long channel; one side being as hard as flint, and the other much softer.*

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* Nearer four thousand miles. See Book of Science, pt. i. p. 32.

† Sir Thomas Pope Blount's Natural History, pp. 229—231; from Travels in Hungaria, &c., by Edw. Browne, M.D.

This defective and laborious method of working the mines in South America, seems to have been retained till the foundation of independent states in that part of the new world, on the ruins of the long misgoverned Spanish colonies. The improvements which have taken place, however, have been chiefly, if not entirely, owing to the investment of British property in the mines of Peru. Fifteen or sixteen years since steam-engines were sent from England, which were used in working the shallow mines of Pasco; and as Mr. Phillips observed, "It may be assumed that the superior skill of British miners, assisted by the power of the steam-engine, where wood or coal is found in sufficient abundance for fuel, will be able to accomplish much more than could be performed by systems so rude, if system it could be called, where no regularity existed in the underground workings."†

The principal mining districts in South Britain, whence metals are procured, are in Cumberland, Lancashire, Derbyshire, North Wales, and Cornwall. Those parts of the north of England in which lead is chiefly found, are more mountainous than the metalliferous tracts in Cornwall, and the mines in general are in elevated situations; and not being very deep, the water may be readily discharged by cutting a passage or adit, through which it may flow into the valleys, and thence to the sea. Hence steam-engines are but little needed, and a very great expense is saved. But in the mining districts of Cornwall steam-engines, and some of enormous power, are constantly used; the water-wheels being comparatively few. The mining tracts are but little elevated, seldom exceeding 500 feet above the level of the sea; and the streams of water are but inconsiderable in point of dimensions or power.

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* Sir T. P. Blount's Natural History, pp. 242—244.

† Outlines of Mineralogy and Geology, 4th edit. p. 196.

In Cornwall, it has been observed, that the difficulty is not where to find a vein, but where to find a good one. A good neighbourhood; a fine *gossan* (a loose, friable, ochreous substance, principally siliceous) in the upper part of the vein or lode; plenty of black Jack (blende), for "Black Jack," says the miner, "rides a proud horse:" and if, at some little depth, on cutting the lode, the mine is inundated with water, these are symptoms of encouragement for the miner, even if little or no copper ore should appear near the surface. Having selected the vein he means to work, and secured the right of working it, by obtaining a lease of the mine for a term of years, it is necessary to determine what part of the vein to begin upon, which however is often decided by convenience, or the facility of bringing up to it an adit from the lowest ground within the settled limits. The next object is to sink a shaft, the underlie of the lode being first determined, often by sinking down a short distance from the surface *on its course.* The shaft, however, is seldom continued in this direction, but is in general carried down vertically.

Thus if a copper lode or vein runs east and west through a hill, the adit is driven from near the base of the hill to the lode underlying north, and through it to the shaft, which is perpendicular. The place of the shaft on the surface is to be determined by the underlie of the lode; from knowing which the miner decides on sinking his shaft, so as to cut or traverse the lode at a particular depth beneath the surface, according to circumstances. When the miner wishes to examine the lode above the level of the adit, he forms a cross-cut or passage from the shaft to the lode, and in the same manner other cross-cuts may be made below the adit, running parallel with it, and extending to the lode. In either case he may be incommoded by water, and consequently it will now be necessary to erect machinery near the mouth of the shaft, for the purpose of raising and discharging the water; and it will also serve to raise the ore, as well as any rubbish which requires removal from below. Thus the miner may continue to explore the lode to such a depth as he thinks proper, or as far as he can conveniently. Should he perceive indications of a rich lode, however, instead of making more cross-cuts, he will probably be induced to extend his working horizontally in the lode itself, as far as may be desirable in either direction, examining it thus in several places, and hollowing out as he proceeds those passages in the mine which he terms levels. As the cross-cuts are generally ten fathoms apart, he describes the place in which his work is proceeding, in raising ore, for instance, by saying that it comes from the ten or twenty fathom level going east or west from such a shaft, each shaft having its own designation; but only such levels are reckoned as are below the adit. In sinking the shaft, or driving the cross-cut, or extending on the lode, the miner sometimes finds that he is in want of air; not that the fire-damp occurs, as in some coal-mines, causing so many fatal accidents in the mines of the north of England; but that the vital part of it is so nearly consumed, that the very candle burns dimly; and this would be a sufficient indication to the miner, even if his own breathing were not affected by it. This want of air, however, is rarely felt when there are in the mine several shafts connected by underground workings; and when it does happen, a supply of atmospheric air is obtained by means of a pipe or trunk of wood or metal, extending from about six feet above the surface to the lowest part of the workings, or to such a place as may be most convenient, and having on the top a wooden box turned to the wind; and there is a more effectual mode, which consists in placing on the top of a pipe, the upper part of which is of iron, a small stove or grate, containing coal, inclosed in such a manner that the fire can only be supported by drawing its supplies of air from the bottom of the workings; and thus the foul air passes up the pipe, and a constant current is kept up; the candle then resumes its splendour, which, however, is but feeble at the best, and the miner breathes more freely.

If the quantity of water which enters the mine be so great that it cannot be discharged fast enough by a horse-wheel and buckets, and circumstances do not admit of the erection of a water-wheel sufficiently powerful, the only resort is a steam-engine. Two large steam-engines are not uncommonly employed in one mine; and there are many instances in which one engine, with its apparatus and pumps, together with the expense of sinking a large shaft on which to place it, have cost more than ten thousand pounds. The miner does not calculate the power of his engine with reference to horse-power, but by the diameter of the cylinder. The cylinders of the largest engines in the county are 91 inches in diameter; there are two of 90 inches on the consolidated mines. As an extreme instance of the prevalence of water in some mines, it may be mentioned, that from one in the western part of Cornwall, not many years ago, after a long series of very wet weather, the engines were computed to draw off 1600 gallons every minute, day and night, during six weeks. The steam-engine or engines are commonly placed on the largest and the deepest shafts in the mine. An ordinary shaft, or one which is only to contain the ladder (for the miner always descends by the ladder, never by the rope, as in coal-mines), is only just large enough for that single purpose; but the engine-shaft, as it is termed, is generally large enough to admit of two divisions, one for the pumps, and another for the bucket or *kibble*, and sometimes a third division as a footway or ladder; and the bottom of this shaft is generally the deepest part of the mine, and is termed by the miner the *sump*. In the bottom of it, to which the pumps extend from the summit, the waters of the mine collect by means of the underground workings connected with it, and the incessant drainage into it from the country or rock, in which the mine is situated. But besides being employed in discharging the water of a mine, the steam-engine is sometimes used for the raising of ores, which it does with a rapidity far greater than can be attained by any other means; sometimes, however, very small engines, termed steam-whims, are erected for this purpose alone, in such mines as are very rich.*

Dolcoath mine, situated at the northern foot of Carnbrae, a granite hill, contiguous to Redruth on the west, is one of the deepest, if not the deepest in Cornwall, being about 250 fathoms from the surface to the sump. This mine has been working above fifty years, and is still rich, and its underground workings are very extensive. The copper-mine of Ecton, in Staffordshire, is now worked at the depth of 472 yards, being the deepest in England. The deepest mine in Europe, or in the world, is said to be that of Truttenberg, in Bohemia, which is worked 1000 yards below the surface.

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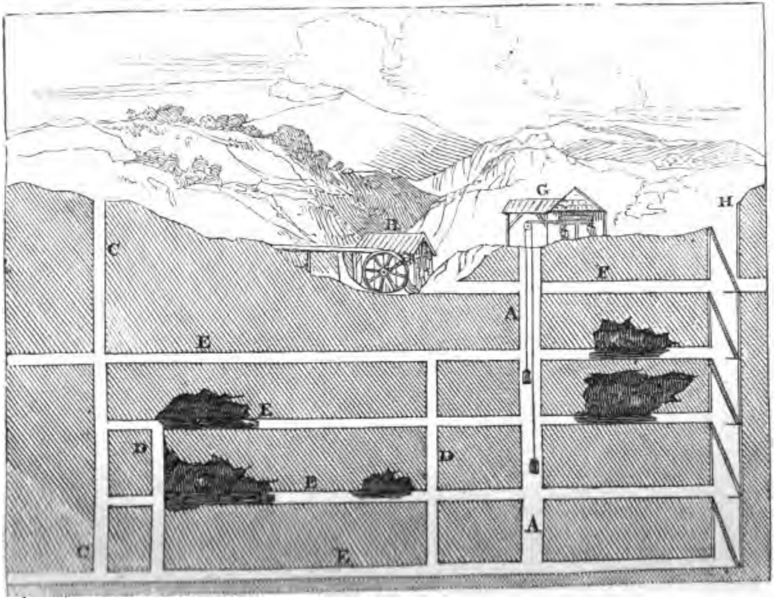
* See Phillips's Outlines, p. 198, &c.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The preceding section of an extensive mine will serve to give the reader some notion of the forms and directions of the shafts, galleries, or cross-cuts, and other works requisite for the extraction of the ores of metals from the bowels of the earth.

A. Principal shaft, for raising water and ores: this pit communicates above with a horse-wheel, and lower down with the adit F, and inferior galleries or cross-cuts.

B. Water-wheel to work pumps or other machinery in the adit or gallery F.

C. Large air-shaft, communicating with the lowest gallery.

D, D. Shafts of communication between the galleries.

E, E, E, E. Galleries at different depths, in the line of the vein or lode, for the extraction of ores or water.

F. Principal gallery, or adit, for the discharge of water, raised into it by pumps, or descending from works in the higher part of the mountain in which the mine is situated.

G. Horizontal wheel (worked by horses), round barrels fixed to the axis of which pass ropes, extending over pulleys, and descending into the shaft A.

H. Large shaft traversing the lode, extending from the surface to the bottom of the mine, and serving for the descent of miners, and as an air-shaft. Stages or floors are placed in it at short distances, to lessen the danger of accidents.

Such are the usual arrangements adopted for the works of mines, in most situations, and under favourable circumstances. In particular cases, however, additional constructions are required for the prosecution of such undertakings. The galleries of some mines are extended under the bed of the sea, when of course especial attention must be paid to the support of the roof of the mine.

Perhaps the most remarkable work of this description was a mine opened more than a century ago, in the midst of the sea, near the port of Penzance. At low water in this place a gravelly bottom was left bare, in which appeared a multitude of small veins of tin ore, crossing each other in every direction. The subjacent strata also contained this mineral in considerable quantities; and works were carried on in the rock whenever the sea, the time, and the season would permit, until the depth became too great.

The place where this submarine tin ore was found was about two hundred yards from the shore; and the bank of the sea here being very steep and high, the distance is considerable, even at low water; and at high tide the rock is covered by three fathoms of water. As the bottom is gravelly and full of rocks, the waves become much agitated, and rise to a great height when the wind blows from particular points. This inconvenience takes place throughout the winter, and had always led to the failure of different attempts which had been made before to drain the mine and raise the ore. At low water-mark, the rock appears a little above the surface of the sea; but during some months in the year it is never uncovered.

Against all these difficulties a single individual, whose property was not worth three crowns, and who undertook the work anew, had to contend. This courageous miner employed three summers in sinking a pit, during which time he could only work two hours a day, and every time he went to work he found his excavation full of water, which he was obliged to empty out before he could recommence working; and this occasioned great difficulties when he set about blasting the rock. He therefore built round the mouth of the pit a turret of wood, impervious to water, or a sort of coffer-dam, and by this means was able to prolong the time of working on the rock. And by raising the turret above the greatest height to which the sea could reach, he endeavoured to keep out the water entirely.

But here he had new difficulties to encounter: first, to make the turret water-tight; and secondly, to secure it in such a manner that neither the flux nor reflux of the sea, or the shocks of the waves, should overturn it. The rock was, fortunately, of porphyry: not too hard to cut, but still very firm. He shaped the portions he separated from it, and disposed them in a regular manner at the foot of the turret, and closed and corked with oakum and fat cement all the interstices between the wood and the stone, so that the whole was united into one mass. The pit, like all those in Cornwall, was lined with planks, all the joints being well caulked or pitched. When this frame-work was thus constructed, he supported it with iron braces. About the mouth of the pit he raised, upon four great piles, a platform of planks, to support the windlass, which was worked by four men. When with great labour and difficulty the pit and tower were finished, he then reaped the fruits of his industry, and establishing a regular work at Stockwork, he drew from it in a little time a considerable quantity of tin, and put his adventure on a good footing.

There were times, however, when his undertaking was not in such a good state. To save expense and diminish his labours, he attacked the part of the mine overhead, by which means, at high water, the sea penetrated through the chinks of the rock, so that he was obliged to sustain the roof, which was pretty extensive, in some parts by planks and thick props, to prevent the great mass of water which pressed on it above from driving it in. Besides this, notwithstanding all his endeavours, it was not possible to keep his wood-work water-tight in the winter, and when the sea was rough, he could not transport the ore ashore in his boat. In the autumn of 1790, the chamber excavated in the inside of the rock had the following dimensions:

Greatest depth . . .	36 feet.
Depth to the level of the passage .	26 feet.
Greatest diameter of the chamber .	18 feet.
Least diameter . .	3 feet.

Four men in two hours emptied the pit of water by the windlass, at the rate of four tons in a minute, towards the end of which time, six men drove it from the bottom of the pit, and poured it into the passage. After drawing out the water, they worked six hours on the rock. From one tide to another, they raised about thirty sacks of ore, each sack containing fourteen gallons, fifteen-sixteenths of which were so rich, that they produced one-sixth of a hundredweight of tin, and one-sixteenth of a hundredweight was procured from the remainder: so that in six months they raised to the value of 600*l.* sterling of tin. As most of the ore was interspersed in a hard rock, difficult to pound, the undertaker had it roasted in a common lime-kiln, which answered perfectly well. There had been nothing of the kind done in Cornwall before. This singular work was known by the name of Wheal Ferry; the persevering individual who planned and executed it, died at the age of seventy years, in the winter of 1791, the mine having in the preceding year yielded ore worth 3000*l.*

The works thus ingeniously constructed, were subsequently destroyed by accident, and the mine was ruined.*

In and on every extensive mine from one thousand to fifteen hundred men, women, and children are employed. The men and the elder boys alone descend the mines and work underground; the women break in pieces the ore with hammers, and the children pick and sort it. The best ores are at once broken small by the double-handed hammer, and put to pile, being in that state merchantable; the inferior ores are broken by single-handed hammers, and sorted, the poorest are committed to the stamps, which are piles or heavy beams of wood, shod with iron, and tilted, or raised and let down alternately, by means of an axle turned by a water-wheel; and thus the ore is bruised so fine, that the whole mass has, after being washed, the appearance of slime, and in this condition it is sold.†

The copper ores of Cornwall are not smelted in the county, in which coal is not found, but are shipped, generally at the port nearest to the mine, for Swansea, in the vicinity of which the principal smelting companies have their establishments. Formerly there were one or two companies which smelted in Cornwall, but it seems to be found by experience to be less expensive to carry the ore to the coal, than to bring the coal to the ore. The ore is taken on the backs of mules to the port, or in carts, or in one or two instances by a railroad; and, in return, coal is brought to the mine, shipped from Wales, in vessels which take back copper ore.

DOCIMASY.

The art of assaying minerals, for the purpose of ascertaining their composition, and especially the nature and proportions of their metallic products, is termed Docimasy, or Docimastics. It differs from metallurgy in its strictest acceptation, in that the requisite operations of docimasy are performed on a small scale, and without any attempt to those economical considerations which are of so much importance in the processes of the metallurgist. The great object of assaying a mineral, is to form an accurate estimate of its component parts and their relative proportions, and thus to discover whether it is rich enough in metal to pay the expenses of working a mine, and reducing the ore to the metallic state. These preparatory operations are peculiarly requisite, with regard to minerals or mineral products containing the precious metals, because a knowledge of the exact quantity of metal in any substance, especially if the quantity be comparatively small, must be obtained before it can be possible to decide whether it will be worth while to undertake its extraction.

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* Dr. Lardner's Treatise on the Progressive Improvement and Present State of the Manufactures in Metals, vol. iii. pp. 15—17.

† Phillips's Outlines, pp. 207, 208.

There are three modes of conducting docimastic operations: 1. The mechanical assay; 2. The assay by the dry method; 3. The wet assay.

Mechanical Assays.

Processes of this nature merely consist in the separation of substances mechanically mixed in metallic ores, and are executed by sifting, washing, and thus removing the soluble and lighter portions of the substance to be examined, so that the metallic particles may be obtained in a separate state. To make an assay by the mechanical method, the ore having been pulverized, a certain quantity of it, by weight, is to be put in a sieve with a little water, and then, by agitation, the lighter matters may be separated from the metallic particles, in consequence of their superior specific gravity. Thus a moist mass, or *schlich*, more or less pure, will be obtained, from which a judgment may be formed of the quality of the ore, and from this mass the whole of the metal may be extracted by assaying it, either in the dry or in the wet method. Washing is practised as a method of assaying auriferous and stanniferous sands, or with regard to schlichs, which have been already washed, to ascertain the degree of purity to which they have been reduced. This mode of assay may be also advantageously employed to separate the oxide of tin, and the sulphurets of lead and antimony, from the gangues or stony matter in which these ores are frequently disseminated. The same kind of assay may be properly used to discover whether scoriæ, or other products of the furnace, retain enough metallic matter to make it worth while to treat them on a large scale by stamping and washing.*

Assays by the Dry Method.

The dry mode of assay has for its object the discovery of the nature and quantity of the metals contained in any ore, but to prevent needless experiments, it is desirable to be able to decide beforehand what metal may be supposed to exist in a fragment of an ore about to be submitted to examination. To obtain this previous information, attention should be paid to mineralogical characters, which will often afford positive indications of the nature of the mineral; but when there is any room for doubt, it becomes necessary to vary the mode of inquiry, and submit the substance to a twofold operation. Thus the mineral fragment to be assayed is to be divided into two portions, one of which may be analyzed with a view to discover the precise nature of the metal, and the other to determine its proportion relatively to the other substances with which it is mixed.

Assays by the dry method require great skill in the operator, and but an inconsiderable apparatus. They may be performed generally in workshops, and they become peculiarly necessary in those where ores are purchased from different localities; because, when the quantity of metal they afford can be ascertained, it becomes easy to fix the price that must be given for the ores. These assays are performed by submitting the mineral body to the action of fire, either by means of cupels, retorts, matrasses, crucibles, or by the blowpipe. It is frequently requisite in these operations to add a flux, or some other substance which may facilitate the decomposition of the ore.

The blowpipe is peculiarly useful in conducting assays, in consequence of its ready application, without loss of time or trouble, as it affords a simple and convenient method of heating to a high degree very quickly, any substance sufficiently small to be involved in the flame excited by this instrument. There are a variety of forms of the blowpipe, among the most convenient of which are those of Dr Wollaston, described by Mr. Brande, in his Manual of Chemistry.

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* Métallurgie Pratique, pp. 33, 34.

vol. i., and that of the Swedish chemist, Gahn. This blowpipe is composed of four tubes: 1. The principal tube or mouthpiece of the blowpipe; 2. A cylindrical chamber to collect the water formed from condensation of the moisture of the breath; 3. The beak, at the extremity of which is, 4. The jet-pipe, through which the air escapes. The jet may be formed with an opening more or less minute, to suit particular purposes. This blowpipe, when taken to pieces, may be fitted into a box or case, adapted to the pocket, so that it may be ready for use in any situation.

In employing this instrument, it must be held in the hand with the larger end of the tube introduced between the lips; then the beak of the jet being approached to the flame of a wax candle, or that of a lamp, with a wick of a proper size, on blowing through the pipe the flame will be projected upon the substance to be assayed. A large wax candle will be found to supply the best flame, which, when urged by the blast, exhibits a double figure, the internal flame being conical, blue, and well defined, and at its apex the most intense heat is excited; the external flame, encompassing the other, is red, vague, and undetermined, and much inferior in temperature. Some attention is necessary to acquire the habit of properly using the blowpipe, so as to throw the flame regularly and uninterruptedly on the body to be examined, and also to continue the blast during a sufficient time without fatigue and exhaustion. This object may be attained by first filling the mouth with air, which is to be driven through the tube by the pressure of the muscles of the cheeks alone, those of the chest not at all contributing to the keeping up of the blast. To renew the air in the mouth it is necessary to respire only through the nostrils, which may be done without discontinuing the blast, and thus a person may continue blowing a long time without inconvenience. The substance to be submitted to the action of the blowpipe, should not be larger than a peppercorn, and it may be placed on the extremity of a slip of platina, or held in a pair of pincers of that metal, or else laid in a small cavity on the surface of a piece of charcoal. In the latter case the charcoal should not be that of fir, or any other wood which would be liable to sparkle in burning, and the cavity in which the mineral is laid may be covered with another piece of charcoal, only leaving an opening for the access of the flame. In most cases, instead of exposing the mineral merely to the action of the flame urged by the blowpipe the substance is pulverized, and mixed, either with oil or with water, and some proper flux; and a small pellet thus being formed, is to be submitted to the flame, and it will thus be less exposed to be driven off when the action of the fire becomes violent.

When a mineral substance is heated at the extremity of the flame, on platina or charcoal, uncovered and exposed to the air, it may become oxidated; but when, on the contrary, it is heated without the contact of air, which may be done by covering it with charcoal, or projecting the flame so that it may environ the body on all sides, it will become disoxidated, either entirely or in part, if it contained oxygen. The results in either case will consequently be very different, for the first is termed the fire of oxidation, and the second the fire of reduction.

When it is requisite to oxidate a metallic substance, combined with any flux, it must be heated intensely, and when fused, gradually withdrawn from the point of the blue flame, and the operation repeated as often as may be necessary, using a jet of large aperture. The oxidation may also be accelerated by the addition of a small quantity of nitrate of potash. In order to reduce the metallic oxides, the glass bead formed by the substance to be examined, and the flux must be kept in fusion on charcoal as long as it remains without being absorbed, that the metallic particles may collect into a globule on the surface of the charcoal. It is then to be fused with a small quantity of subcarbonate of soda, which will be absorbed by the charcoal, and the spot where the absorption has taken place must be strongly ignited, by using a tube with a small aperture. By continuing the ignition that portion of the metal not before reduced, will be brought to the metallic state, and the process may be quickened by placing the globule in a smoky flame, so that it may become covered with soot. The beads which contain metals frequently exhibit a metallic splendour, especially if exposed to a gentle flickering smoky flame after the intense heat has ceased. With a moderate heat the metallic surface remains, but after a little practice it may be ascertained without difficulty, whether any metal is contained in the body under examination. It should be observed that glass of borax alone sometimes assumes, externally, a metallic lustre. When the experiment is concluded, and the charcoal become cold, that part impregnated with the fused mass must be cut out and rubbed down with distilled water in an agate mortar, the soda which formed the flux will be dissolved, the charcoal will float on the liquid, and may be poured off; any of the metallic particles remaining at the bottom may then be examined. By this mode of assay most of the metals may be reduced.*

Assays by the Moist Method.

When an ore is examined by the moist method complicated processes sometimes become requisite, for the management of which a considerable degree of skill in chemistry must be acquired; but this method presents important advantages in practice. The assay of ores by the moist mode consists principally in exposing them to the action of acids, alkalies, or neutral salts, and when solutions have thus been obtained, the metals may be precipitated by proper additions, and a judgment of their nature formed from the colour or other sensible properties of the precipitates. Thus metallic solutions may be analyzed by the application of tests, but in order to discover the relative quantities, as well as the qualities of a mineral, by the moist assay, the metals must be precipitated from their solutions, and the products edulcorated and weighed.

Gold may be tested by exposing it to the influence of nitric acid, which acts upon almost all other metals, but leaves the gold untouched.

Silver ore may be assayed by reducing a small quantity of it to fine powder, digesting it in nitric acid, and mixing the filtered liquid with a solution of common salt (chloride of sodium). A chloride of silver will then be precipitated, containing, when dried, 75 per cent. of metal; or the chloride may be reduced by fusing it with three times its weight of subcarbonate of soda.†

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* For particular information relative to the analysis of Alloys by Cupellation, see Children's Essay on Chemical Analysis, pp. 96—108; and for the methods of making exact assays of the more important metals, see Métallurgie Pratique, pp. 39—66.

† Report of Brande's Lect. on Mineralog. Chemistry, in Journ. of Science, vol. iv. p. 245. A convenient method of reducing chloride of silver is mentioned in Annales de Chimie, t. xiv. p. 319. Put the chloride into a small vessel of zinc or cast iron, containing a little water; and leaving it there a short time, if the vessel be clean, the decomposition will soon take place, otherwise a little muriatic or sulphuric acid may be added. The metallic product may be washed with muriatic acid.

Iron ore is sometimes treated in the moist way, in order to discover whether it contains phosphorus, which would destroy the malleability of the metal. In this case the ore supposed to contain phosphorus must be mixed with one-fourth of its weight of nitrate of potash, and placed in an earthen crucible, which is to be strongly heated for half an hour; then the mixture, being withdrawn from the crucible, must be lixiviated with a small quantity of distilled water and filtered: the liquor obtained is now to be assayed by the following process: After it has been neutralized by nitric acid, a solution of chloride of lime is to be poured over it, and the liquor will not become clouded unless a small portion of carbonate of lime should be formed, which must be separated by filtration; then a little ammonia must be added, and if a white precipitate is formed in consequence of this addition, it will be a proof that the ore contained phosphorus, the white precipitate being phosphate of lime.

The analysis of copper ore by the moist method is effected by treating the roasted mineral with nitric acid, and by adding ammonia in excess, the oxide of copper will be dissolved, and the other metallic oxides partly precipitated; then the alkaline solution of the metal after being filtered, is to be saturated by an acid, and the copper may be precipitated, in the metallic state, by plates of polished iron.

The moist method of assay may be employed in analyzing the ores of lead, and the products of the foundries. The roasted ores must be dissolved in nitric acid somewhat lowered, and the solution is to be diluted with water, and precipitated by a sufficient quantity of some soluble sulphate, which forms with the oxide of lead, sulphate of lead. The precipitate being washed and dried, always contains sixty-eight per cent. of metal. In this mode of assay the silver which may be contained in the ore will also be precipitated in the state of sulphate. When it is necessary to assay sulphates of lead, either alone, or mixed with other substances, the muriatic must be employed instead of the nitric acid.*

Solutions of the various metals may be tested, and their nature ascertained to a certain extent, by observing the effects of the addition of certain bodies called reagents, and noting the colours and other sensible properties of the precipitates thence produced.

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* Métallurgie Pratique, pp. 47, 51, 59.

Thus tincture of nutgalls turns the solution of iron black, and the solution of lead white, and with other metallic solutions, yields green, yellow, brown, or blue precipitates.*

METALLURGIC PROCESSES FOR THE REDUCTION OF MINERALIZED METALS.

The operations requisite for obtaining metals in a pure state from their several ores constitute the proper subject of metallurgy. The methods adopted for effecting the reduction of metals, must necessarily be varied according to the nature of the metal to be obtained in any given case, and that of the substances with which it may happen to be blended. Hence a diversity of processes will be required, even with regard to a single metal. They may, however, all be referred to three kinds, like those of docimasy, consisting of mechanical operations, chemical operations in the dry way, or by means of fire, and operations in the moist way, chiefly by employing mineral acids. But in almost all processes for obtaining metals from their ores, the mechanical and chemical methods are more or less combined according to circumstances.

Metallurgic chemistry includes the art of forming compound metals, or alloys, some of which are more serviceable for certain purposes than any of the simple metals. This branch of knowledge it will be perceived, affords an extensive field for research, presenting to our notice many subjects extremely interesting, not only to artists and men of science, but especially to all persons engaged in the study of mineralogy and geology. In the few remaining pages to be devoted to metallurgy, nothing more can be attempted than the introduction of some general notices of the processes employed in the reduction and refining of the principal metals, and in the formation of the most useful alloys, such chiefly being selected as may tend to show the connexion between the subject before us, and the other branches of science to which this volume relates.

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* In Dr. Henry's Elements of Chemistry, vol. ii., is given a table of precipitates thrown down from metallic solutions by the following reagents: (1.) Prussiated Alkalies; (2.) Tincture of Galls; (3.) Water impregnated with Sulphuretted Hydrogen; (4.) Hydrosulphurets.

Reduction of Ores containing Gold.

As gold is not found mineralized, or in the state of proper ore, but either pure, or else combined with some other metal to form an alloy, the metallurgic processes for reducing it are in general less complicated than in most other cases. This metal is derived from two sources, being either mixed with sand, gravel, and earthy matter, in valleys, ravines, and the beds of rivers, or occurring in veins, and procured by mining like metals in general. The modes of treatment requisite to procure gold in a state of purity, vary according to the state in which it is found in the situations just mentioned.

Gold obtained from alluvial soils in pallets or grains, may be separated more or less from the substances by which it is contaminated by washing. This operation is performed frequently on the spot where it is procured. Thus the gold-seekers sometimes wash the auriferous sands in a sieve held in the hand; or else use inclined tables, which being covered with coarse woollen cloth or rough hairy hides of animals, the earth and sand taken up in small quantities is thrown on the table, over which a stream of water being poured or conducted, the lighter substances are washed away, and the particles of gold detained by their superior weight on the surface of the cloth or skin. But this method has the inconvenience of not separating the heavier portions of gravel which become entangled among the hair or wool together with the metal. The gold thus obtained may be further purified, according to circumstances, by amalgamation with mercury, or by cupellation.

Gold is also found pure in veins, but sometimes in a state of minute division, and so blended with other bodies, as to require various operations for its extraction. It is thus procured in Hungary, and in this case the whole contents of the vein holding small particles, or strings or little nests of native gold, are brought to the surface, broken into small pieces, and carefully sorted, the grains where perceptible being detached from the matrix, which is chiefly quartz. The poorer parts are then stamped, by beams of wood shod with iron at the lower extremity, worked by a water-wheel, and thus the ore is crushed to a powder upon an iron plate. This powder is damped by throwing water containing salt upon it; and a quantity of mercury being put into a bag of porous leather is forced through the pores, and dropping on the damped powder in a minutely divided state, is kneaded up with it. The paste containing mercury and gold thus incorporated, is afterwards heated in a proper vessel to about the temperature of boiling water for three or four days; the mixture is then washed carefully by small parcels at a time, so that the earthy particles are washed off, leaving only the amalgam of mercury and gold. Part of the mercury is then separated by pressure in a leathern bag, and the rest is driven off by distillation, leaving behind the gold, and also any portion of silver with which it may be alloyed. When gold occurs in a matrix consisting of iron pyrites, galena, &c., in which the gold exists in invisible particles, the masses of ore are broken by hand into small pieces, and then placed beneath the stamps to be reduced to powder, which is carried by a stream of water to a series of pits, in which the heaviest particles subside, the lighter earthy matter being carried away by the current. After repeated washings, the metallic parts, consisting principally of iron pyrites and galena, are roasted in a reverberatory furnace, with a proportion of quicklime, at a red heat, but not so as to fuse the mass, until part of the sulphur is driven off; the fire is then increased, and the whole brought to a state of thin fusion, and then let out into a mould of sand. During the fusion the iron, on account of its strong affinity for sulphur, resumes the portion of which it had been deprived by previous roasting, by decomposing the sulphurets of lead, copper, &c., with which it is mixed; in consequence of which these metals, by specific gravity, fall in drops through the vitreo-ferruginous scoriæ, carrying with them the gold and silver, and unite at the bottom in a dense metallic mass. Hence the pig that is formed in the mould of sand is found to consist of two parts adhering to each other, but easily separable by the hammer; the uppermost and largest portion is composed of cellular scoriæ, beneath which is a black heavy compact mass containing the gold and silver, together with lead, copper, some sulphur, and iron; this is now broken into small pieces, and roasted and fused once or twice more, until the sulphur and other impurities are separated, leaving nothing but the gold, silver, lead, and copper.

The separation of gold from lead is effected by cupellation. The cupel or test is a porous, infusible, earthy mass, with a hollow concavity at the top for the reception of the metals; this being placed in a furnace, so as not to be in contact with the burning fuel, and a current of air at the same time passing over the surface of the test, the metal is brought almost to a state of ebullition. At this temperature the lead becomes changed to the state of a vitreous oxide, which, sinking into the pores of the test, leaves the gold behind; and if the ore contained silver and copper, subsequent processes will be required to effect their separation.

Reduction of the Ores of Silver.

Silver is extracted from its ores either by smelting in a manner similar to that practised with regard to other metals, or by amalgamation with mercury. The processes carried on at the extensive amalgamation works of Freyberg, the capital of the mining district of Saxony, and where one chief advantage of this mode over smelting is the saving of fuel, are described with scientific minuteness by J. H. Vivian, Esq., in the Annals of Philosophy, vol. xxvii.; and an abstract of this descriptive statement may be found in the third volume of Dr. Lardner's Treatise on Manufactures in Metals.

Silver like gold frequently requires to be subjected to the process of cupellation, to separate it from oxidizable metals. This method of purifying silver is adopted in Persia, and the following account of it as given by Oostad Muhammed Ali, a Persian, who visited this country, was published in Brande's Journal of Science, vol. viii.:

Persian Metallurgical Process for the Purification of Silver.—A sort of basin is made, either by excavating the ground, or by arranging stones in a circle. This is from nine to twelve or fourteen inches wide, and is incomplete at the side in one place, for the reception of the fuel, which by its combustion is to melt the metal. The fuel consists of two large and long logs of wood, which are placed with their ends in the aperture on the edge of the basin. These ends are lighted by placing on them burning fuel, and then the blast from a pair of bellows is directed so as to pass across the fire, and thus drive the flame and heat into the basin, acting as a large blowpipe. Lead containing silver, or impure silver with the addition of lead, is then placed in the basin, and being soon melted and heated by the flame, it is purified as by common cupellation. The litharge (vitrified oxide of lead) is forced off to the sides as it is formed, and either absorbed or lost, and as the wood burns away before the blast of air, the logs are thrust onward until all is consumed; then fresh logs are supplied, if necessary, or the process stopped, as may be found convenient.

"The singular fact has been ascertained, that silver in fusion absorbs oxygen, which, on solidifying, it parts with; and Gay Lussac says, that it thus gives out twenty-two times its own volume, and that the presence of a very little copper destroys this property."*

The attraction of both silver and copper when in fusion for oxygen, was observed several years since by Mr. S. Lucas, of Sheffield, who stated the result of his observations in a letter to Mr. Dalton, published in the Manchester Transactions. He found that silver in a fluid state absorbed oxygen, not only from the atmosphere, but also from other bodies which give it out when heated, as some of the nitrates. If silver in large quantities, after being exposed when melted to a current of oxygen gas, or atmospheric air, be allowed to cool gradually, the surface first becomes solid, then soon bursts, ebullition ensues, and an elastic fluid escapes, driving before it a portion of the internal fluid metal, and causing protuberances on its surface. Substances which have a strong attraction for oxygen placed in contact with the melted metal, prevent the ebullition from taking place. Thus charcoal spread for a few minutes on the surface of the silver in fusion absorbs the oxygen which it may have acquired, and no escape of gas or appearance of ebullition then occurs, whether the metal be cooled slowly or hastily.†

Reduction of Crude Platina.

Platina is never mineralized, but it is often debased by intermixture with other metals; and in the state in which it is imported from South America, the crude metal contains silica, mercury, gold, palladium, rhodium, iridium, osmium, iron, copper, and lead, as well as platina. This last metal may be separated from the other bodies by the following process: The mercury is to be driven off by exposing the ore to a considerable degree of heat, an operation which renders the platina yellower, in consequence of the appearance of grains of gold. The residue may be digested in nitro-muriatic acid, diluted with its bulk of water; this takes up gold, iron, and a little platina: if the remaining ore be now digested in nitro-muriatic acid, by far the largest portion will be dissolved, and there will remain a black powder; to the nitro-muriatic solution add a solution of muriate of ammonia, which will occasion the precipitation of the greater part of the platina in the state of a very difficultly soluble ammonia-muriate, and which may be separated upon a filter. In the filtrated liquor immerse a plate of zinc, which will throw down lead, rhodium, palladium, and a portion of platina. the lead may be separated by very dilute nitric acid: dissolve the residue in nitro-muriatic acid, add common salt, and evaporate to dryness. this residue, composed of the soda-muriates of platina, palladium and rhodium, is to be digested in alcohol, which dissolves the triple salts of platina and palladium, but not that of rhodium, which therefore is thus separated: to the alcoholic solution add solution of muriate of ammonia, which throws down the platina, and leaves the palladium in solution, which may afterwards be precipitated by ferrocyanate of potassa. The insoluble black powder, by alternate fusions with potassa, and boiling in muriatic acid, may be resolved into osmium soluble in the alkali, and iridium in the acid.

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* Donovan's Treatise on Chemistry, p. 241.

† Journ. of Science, vol. iv. pp. 169, 170.

The yellow precipitates formed by the addition of muriate of ammonia to the alcoholic solution of the salts of platina and palladium consisting of ammonia-muriate of platina, must then be collected, edulcorated with warm water, and dried. It must next be distributed into saucers, which are to be introduced into a small oven, and exposed for a short time to a low red heat, in order to drive off, by sublimation, the greater part of the muriated ammonia. When withdrawn it will form a spongy mass of a grey colour. About half an ounce of the platina in this state is to be put into a strong iron mould about 2½ inches long by 1½ wide, and is to be compressed as forcibly as possible by striking with a mallet upon a wooden pestle, cut so as accurately to fit the mould; another half-ounce is then added and treated in the same manner, and so on till six ounces have been forced into the mould: a loose iron cover, just adapted to fit into the mould is then laid upon the platina, and by means of a strong screw-press almost every particle of air is forced out from the metal. This is an important part of the process, for if any quantity of air is left in the mass, the bar into which it is formed will be liable, in the subsequent operations, to scale and be full of flaws. The pressure being duly made, the mould is to be taken to pieces, and the platina will be found in the form of a hard, compact parallelopiped. It is now to be placed in a charcoal forge fire, and exposed to the most intense white heat, in order completely to drive off the remaining ammoniacal muriate; this being done, it is to be quickly placed on a clear, bright anvil, and gently hammered in all directions with a clean hammer. This must be repeated several times; after which the mass will be perfectly compact, and fit to be laminated or wrought in any other manner that may be required.

Reduction of the Ores of Mercury.

The metallurgic treatment of mercury is very simple, and the metal is extracted chiefly by two methods. The following is the process adopted in the Palatinate. The ore is to be sorted, pulverized, and mixed with quicklime or slaked lime; and the richer it is in metal, so much greater must be the proportion of the lime. The mixture is then introduced into large cast-iron retorts, which are placed in two ranks, one above the other, in a long furnace; and each retort is to have attached to it without luting a glass receiver, one-third part filled with water. The furnace is then to be heated, at first gently to drive off the moisture; after which, the juncture of the vessels must be closed with tempered clay, and a full red heat is to be applied for seven or eight hours. The lime will combine with the sulphur contained in the mercurial ore, and the metal will be volatilized and condensed in the receiver. A different method of proceeding is practised at Almaden; and at Idria, where furnaces of a peculiar construction are used, and the reduction of the metal is effected by the oxidation and consequent separation of the sulphur, which forms sulphurous acid, while the mercury is sublimed, and becomes condensed within the apparatus.*

Reduction of the Ores of Iron.

This metal being found in a state of nature, variously combined, different processes are requisite to reduce it to the metallic state. The smelting of iron is a subject of national importance, both in Great Britain and also in other countries; and hence it has not only occupied much of the attention of writers on metallurgy, but it has likewise furnished a topic for distinct and sometimes voluminous treatises. It can here, however, be but slightly noticed, as our limits will only admit of some brief and general statements of the peculiar methods of reducing this metal. Carbonaceous matter of some kind is always largely employed in smelting iron ores; and in some foreign countries, as Sweden, charcoal is used for that purpose; while in Britain there are but few charcoal furnaces, coke being generally employed instead of it. The most abundant of the iron ores, and that which is most largely used in this country, is the common ironstone, which is an impure carbonate of the metal, found in small lumps or layers in the clay which separates the beds of coal.

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* See Métallurgie Pratique, pp. 296—302.

The ore is first reduced to pieces about the size of an egg, and is sometimes roasted in cup-shaped kilns, having lighted coal at the bottom, on which the iron ore is heaped so as to fill the kiln, and the roasting is generally complete by the time the coal is consumed. More commonly, however, the roasting is performed on the ground: four to eight inches in thickness of coal is first laid down, on which is placed a layer of broken ironstone, from eighteen inches to two feet thick; two inches of small coal is then laid on the ore, and on this a pile of ore diminishing in size so as to form a ridge at the top, and the whole is then covered with small coal and coal-dust. The pile is at bottom from thirty feet to sixty yards long, ten to sixteen feet wide, and about five feet high. The lower stratum of coal is then lighted, which by degrees lights the whole mass. In a few days the ironstone, when cool, becomes of a red or reddish-brown colour; and the sulphur, carbonic acid, water, and inflammable matter being driven off, it is fit for the smelter. The furnace in which it is smelted is upwards of forty feet high, and is built of the strongest masonry, externally of the form of a truncated four-sided pyramid, internally of a peculiar figure, and lined partly by fire-bricks and partly by sandstone; and into which when charged, air, in a high state of compression, and sometimes heated previously, is forced. This is a blast furnace, and is charged at the chimney by regular intervals with coke, iron ore, and limestone in the proportion of about 4 of the first, 3½ of the second, and 1 of the third by weight; and is always kept so charged to a certain height

In somewhat more than forty-eight hours the whole runs down, and the iron being melted, is suffered to flow out into furrows made in sand, where it forms pig iron; or into a large reservoir, whence it is poured by means of ladles into moulds, forming all the various articles of cast iron ware, from cannon and steam-engine boilers to fire-grates and common iron pots.

There are several varieties of iron to be found in commerce, the most important of which are cast iron, wrought iron, and steel. Of *cast iron* there are two principal kinds, called respectively white and grey iron. White iron is very hard and brittle, and exhibits a radiated fracture, being composed of a congeries of laminæ, variously aggregated. Acids act upon it but slowly. Grey or mottled iron is softer and less brittle than white, so that it admits of being bored or turned in a lathe. The texture of the metal gives it the appearance of bundles of minute fibres. Cast iron, after having been in some degree refined by fresh fusion, in contact with charcoal, is converted into *wrought iron* by a process in this country called puddling. The cast iron is put into a reverberatory furnace, and when in the state of fusion it is agitated, so that every part of the mass may be exposed to the air and flame. After some time the melted metal heaves, a blue flame issues from its surface, it gradually grows tough, loses its fusibility, and becomes pulverulent. The fire is then increased, so that the particles again agglutinate at a welding heat, and are wrought up into separate masses, which, while intensely heated, are passed successively between rollers, and a quantity of carbonaceous matter being pressed out, the metal is rendered malleable. The flattened masses cut in pieces are then placed in parcels in a reverberatory furnace, strongly heated, and again hammered or rolled out into bars. The iron is thus rendered more tough, flexible, and malleable, but at the same time almost infusible, and in this state it appears to be nearly pure. A bar of wrought iron, when its texture is examined, displays a fascioulated appearance, the fibres extending longitudinally, as may be perceived in a bar of wrought iron that has been torn asunder. *Steel* is a compound of iron and carbon, the latter in small proportion, and it is not improbable but it may also contain silicon. It partakes, to a certain extent, of the properties of cast iron and wrought iron, being fusible, like the former, and malleable, like the latter. When it is heated and suddenly cooled it becomes hardened, and by proper management it may thus be variously tempered to form cutting instruments, and for other purposes. When steel is kept for a long time in a state of fusion, its carbon is dissipated, and it becomes reduced to the state of pure iron. Iron is converted into steel by a process termed cementation, which consists in submitting iron with charcoal in alternate layers to the action of heat in a close furnace for several days. *Cast steel* is prepared by melting common steel in a crucible, with a flux composed of carbonaceous and vitrifiable ingredients. It is still more highly carbonized than common steel, as well as more brittle and fusible; and being harder, of more uniform texture, and of more compact grain, it is adapted for all the finest articles of English cutlery. Iron in the process of its conversion into steel acquires a blistered surface, and in this state it is used for some purposes under the name of *blistered steel.* This, when made into smaller bars and hammered, forms *tilted steel*; which, when broken up, heated, welded, and again drawn out into bars, forms *sheer steel.*

Reduction of the Ores of Tin.

The only ore from which tin is procured in this country is an oxide, found interspersed through some parts of the mineral veins in Cornwall, in small crystals, accompanied by masses of slate or granite, sulphurets of iron and of copper, and arsenical pyrites, quartz, and occasionally tungstate of iron and other minerals. It is commonly blasted by gunpowder, and brought to the surface in pieces of considerable size, which are stamped to a fine powder, till the ore has the appearance of slime, and it is afterwards washed on a wooden frame termed a buddle; the stream of water carrying off the lighter earthy particles, and leaving the more weighty grains of tin, which, after repeated washings, are reduced to a state fit for the smelting-house. Being still mingled with other substances, it is in this state termed black tin. This is roasted at a low red heat, in a reverberatory furnace, to volatilize the arsenic and sulphur. It is then of an ochrey red colour, owing to the oxidation of the iron and copper. It is again washed, and the impurities separated from it; and it is then reduced by placing it in a reverberatory furnace, about 7 feet long and 3½ wide, from 7 to 15 hundredweight of the roasted ore being mixed with about one-fifth of Welsh culm (small coal), and in some cases a small quantity of slaked lime, the whole being turned over and moistened with water; a brisk fire is then applied for about six hours, the tin sinking, as it becomes reduced to the bed of the furnace, beneath a surface coating of boiling black scoriæ. The furnace is then tapped, and the melted *tin* suffered to flow into a small cavity at the foot of the furnace. When that is done, the scoriæ are raked off, and a new charge of roasted tin ore and culm thrown in. When the metal in the pit is red-hot, it throws up a quantity of slag, very rich in metal, which is immediately returned into the furnace; and when the melted tin is become sufficiently cool, it is taken out with iron ladles and poured into moulds of granite, where it consolidates, each charge affording on an average from four to five hundredweight of metal. The melted tin thus procured is next placed, without any addition, in a small reverberatory furnace, and exposed to a very gentle heat; the purest part which melts first is drawn off, forming the common grain tin; the more refractory part, containing a small and variable proportion of copper and arsenic, is then melted and cast into pigs of common tin, or block tin.

The finest grain tin, however, is procured from the stream-tin *ore*, so termed because it consists of the loose crystals of oxide of tin found in the rubble or alluvial soil in some of the low grounds of Cornwall, having been washed thither by streams of water. These are free from the impurities of vein-tin ore, and the metal is consequently more perfectly reduced, and by more simple processes.

Reduction of the Ores of Copper.

The copper ore of Cornwall, from which the metal is generally procured in this country, is the yellow sulphuret, a combination of copper with sulphur and iron. The next ore which occurs most abundantly is the sulphuret, containing about eighty per cent. of copper. The oxides, carbonates, and arseniates of copper, are also found here, but in smaller quantities, and they are of less importance. Both arsenic and sulphur adhere strongly to copper; and as a small proportion of either renders the metal brittle and difficult to work, peculiar attention is necessary in the reduction of copper ore, in order that these substances may be separated.

The reduction of copper ore is completed by means of eight processes. The first is that of calcining in a reverberatory furnace, about 17 feet by 19, with a bottom or bed made of fire-bricks. The chimney is from 40 to 50 feet high, which causes such a powerful draught that the arsenic and sulphur, separated in roasting the ore, pass almost wholly through the chimney into the open air. About three tons of the ore are spread over the bottom of the furnace, being thrown in at the top, through a kind of funnel or hopper. The fuel is Welsh coal, which is burnt at the anterior part of the furnace, and its flame passes over the surface of the ore in its passage to the chimney. In this furnace, which is called the calcining furnace, the ore is roasted, without addition, with a dull red heat for twelve hours, being frequently stirred with a long iron rake, to expose fresh surfaces to the action of the flame. The ore is not melted here; but when roasted sufficiently to oxidate the iron, and convert the sulphur into sulphurous acid, it undergoes the second process, namely, that of being melted; and for this purpose is carried to another furnace, about 11 feet by 8, and here it receives a fusing heat, but still without any addition, except a little slag, or, when the ores are very sullen, a little fluor spar to assist the fusion. When the ore is melted, the liquid mass is well stirred, and afterwards the slag is raked from its surface. More calcined ore is then added, and when the furnace is full it is tapped, and the melted metal flows into an adjoining pit full of water, by which means it becomes granulated. The metal in this state contains about one-third of copper, and consists of copper, sulphur, and iron. Five charges are melted in twenty-four hours. In the third operation the granulated metal is calcined to oxidate the iron, and it remains twenty-four hours in the furnace; during which it is often stirred and turned about, the heat being at first moderate, but gradually increased. The fourth process is that of melting, after calcination, in the same furnace, some slags from the last operation being added, and pieces of furnace bottoms impregnated with metal in the form of oxide of copper, which become reduced during this process; the oxygen of the copper combining with the sulphur passes off as sulphurous acid gas, while the reduced metal enters into combination with the sulphuret. The slags being skimmed, the melted metal is either tapped and suffered to run into water, where it is granulated, or else into sand beds, where it becomes solid. Its produce in fine copper is now about 60 per cent. The fifth process is that of again subjecting the metal to the same mode of calcination as in the third process. The sixth process consists in the melting again of the metal, as in the fourth process, and the result is a coarse copper, containing from 80 to 90 per cent. of pure metal. In the seventh process the metal is roasted in the smaller furnace, chiefly to oxidate, and finally to expel the volatile substances. From 25 to 30 per cent. of metal, by this process, becomes fused at the end of the operation, which continues from twelve to twenty-four hours, according to circumstances. The metal is then tapped into sand beds, and the pigs in this state are termed blistered copper. It is now fit for the refinery. The eighth process is that of refining or toughening. This appears to be a delicate process, the success of which depends on several circumstances that are judged of principally by the eye of the workman. It is conducted in a furnace similar to that for melting; and the chief object appears to be that of abstracting from the nearly pure metal the last portions of oxygen, which is effected by adding charcoal to the metal while in fusion, and stirring it occasionally with a pole of birch-wood, until the operator judges it to be pure.

Reduction of Ore of Lead.

The principal part of the lead procured in this country is derived from the ore called galena, which is a sulphuret of lead. Other ores, as the carbonate, the sulphate, and the oxide of lead, are occasionally mixed with the galena, which also frequently contains some silver, and when the quantity is sufficient to pay for the expense of separating it, that process is effected by exposing the roasted sulphuret to the action of air and heat, in shallow earthen dishes. The lead thus becomes oxidated, or converted into litharge; while the silver is left behind, retaining the metallic form. The litharge is afterwards reduced by fusing it with charcoal.

In the usual process for the smelting of lead ore, the galena being freed by the hand and the hammer from all such impurities as can be readily separated from it, is beaten into small pieces, and after repeated washings and cleansings, is placed in a reverberatory furnace at a low red heat for some hours, to drive off the sulphur and arsenic, without fusing the lead; and when the flame on the surface has changed from blue to a reddish white, the roasting is considered as finished, the lead being converted into an oxide. The reverberatory furnace commonly used is about 10 feet long and 6 feet wide internally, and about 2½ feet deep; the fireplace being at one end, from which the flame rises into the furnace. The quantity of ore usually thrown into the furnace at once is sixteen hundredweight, of one hundred and twenty pounds each, which quantity is spread over the floor of the furnace, and the doors are then closed. The roasting, as above mentioned, being completed in a moderate heat, a small quantity of charcoal is added, the doors closed, and the reduction completed; the lead, in a reduced state, lying at the bottom of the furnace, covered by a slag two or three inches in thickness, the slag is then tapped and runs off, and is used for mending the roads. Some quicklime, in powder, is now thrown down upon the metal in a state of fusion, which serves to raise and cake the remaining slag; which, by means of a rake, is taken from the surface, and is nearly black, and very heavy. The lead is then suffered to run out of the furnace into a pan, and the scum or dross being taken from the surface is thrown back into the furnace the lead is, lastly, ladled from the pan into iron moulds, and left t cool. All of these operations are repeated, by means of two sets o workmen, during every seven or eight hours.

Reduction of the Ores of Zinc.

The ore of zinc, whether calamine or blende, is first broken in small pieces, and the galena, pyrites, and other impurities are separated as exactly as possible by the hand; it is next calcined at a moderate red heat in a reverberatory furnace, by which the calamine is freed from its carbonic acid, or the blende from most of its sulphur. It then washed, by which the lighter earthy parts are separated from t metallic oxide, which latter being dried is well mixed with one-eighth its weight of charcoal, by grinding the ore and charcoal together in a mill, as a preparation for smelting. The furnace in which the reduction is performed, is of a circular figure, somewhat like that of a glass-house; in it are fixed six large earthen pots or crucibles, about four feet high, nearly of the shape of oil-jars; into the bottom of each crucible is inserted an iron tube, that passes through the arched floor of the furnace, and dips into a vessel of water placed beneath, while the other end of the tube rises inside the crucible, to within a few inches of its top. These crucibles are filled up to the level of the tube with the mixture of roasted ore and charcoal, the cover of each is very accurately luted, and the furnace is charged with fuel, by which an intense heat is kept up for several hours. The zinc, as it is reduced, ascends to the top of the pot in the form of vapour, and being prevented from escaping by the closely luted cover, it descends through the central iron tube into the water, and is condensed in small drops or globules, which are afterwards melted and cast into ingots.

Common zinc generally contains a little lead, copper, arsenic, iron, manganese, and probably plumbago, which often considerably impairs the quality of the alloys into which it enters. In order to get rid, in part at least, of these impurities, the common practice is to melt the zinc in a crucible, and then to stir into it, by means of a stick or earthen rod, a mixture of sulphur and fat; the latter of these preserves the zinc from oxidation, while the former, uniting with all the metals present, except the zinc, converts them into sulphurets, which, rising to the top, form scoriæ that may be skimmed off; this is to be repeated as long as any scoriæ appear on the surface.

The only metals which have been extensively applied to purposes of utility in the reguline or metallic state, are those, the modes of reducing which have been described in the preceding pages. Besides these, however, the metals called nickel, palladium, and rhodium, have recently been employed by artists,* though only to a very limited extent; and antimony, arsenic, and bismuth, though not used alone in the arts, yet serve by their combinations with certain other metals to form valuable alloys.

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* See Treatise on Chemistry, pp. 157, 160.

Gold in a state of absolute purity is so soft and pliable, that though it possesses a high degree of tenacity, it is by no means so well adapted for technical purposes as some of its alloys. The addition of copper to this metal renders it much harder than before, and gives it a deeper colour. Silver, on the contrary, communicates to gold a lighter tint; and the mixed metal met with in commerce called "gilded ingots," consisting of silver alloyed with a little gold, is as white as pure silver. The gold coin of most European nations contains silver or copper, or both those metals. The standard or sterling gold of this country is composed of twenty-two carats,* or parts of pure gold, and two of copper, which proportions appear, from the experiments of Mr. Hatchett, to form the best alloy for the purpose to which it is appropriated, resisting the influence of friction better than any other which had been tried. Besides jewellers' gold, which ought to be of the new standard, or eighteen carats fine, alloys of almost every degree of deterioration are used for making trinkets and other articles.

"The permanence and beauty of gold renders it a very desirable ornament, while at the same time its extensibility enables us to use it where its expense and weight would otherwise preclude its employment. Where gilding is performed upon metallic surfaces, it is usually done by a solution or amalgam of gold in quicksilver. This is called water gilding, and the process exhibits an instance of the mical attraction, and subsequent decomposition by heat. Steel is sometimes gilded by the ethereal solution of gold.*

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* The mode of computation by carats, with reference to the alloys of the precious metals, has long been employed in England. Every mass of alloyed gold is supposed to be divided into twenty-four carats, and the relative quantity of gold it contains is denoted by the number of carats of that metal in the mass; as gold of twenty-two carats, or standard gold for coin; gold eighteen carats, or gold of the new standard, used for watch-cases, &c. The method does not so conveniently admit of the appreciation of various quantities of alloy, as that adopted in France, where the pure gold in alloys is estimated by thousandth parts: thus gold of eighteen carats, or containing alloy, would by the French method be said to be of the standard expressed by .750.

Silver forms useful alloys with copper, especially for coin and plate. The addition of a small proportion of copper to silver renders the metal harder and more sonorous, without materially impairing its colour. English standard silver is composed of 11.1 of pure silver, and .9 of copper; or 11 oz. 2 dwts. of the former metal, and 18 dwts. of the latter, in a pound Troy weight; which, when coined, forms sixty-six shillings. Copper is plated with silver for various purposes, and by means of different processes. These metals may be united by a mode resembling the operation of welding; a plate of silver being applied to the surface of one of copper, and the mass compressed by passing it between steel rollers; after which it may be worked into different forms for use or ornament. An inferior kind of plated copper is formed by applying to the surface of that metal an amalgam of silver, and the mercury being driven off by heat, the surface is burnished. The brass dials of clocks, and the scales of barometers and thermometers, are silvered on the surface, by rubbing over them a mixture of chloride of silver, chalk, and pearlash.

The compounds of mercury with other metals are called Amalgams. That of tin is extensively used for silvering (as it is termed) looking-glasses. For this purpose tin-foil is spread on a flat stone, and covered with mercury; the glass is then placed upon the metallic surface, and the excess of mercury being pressed out, the remainder amalgamating with the laminated tin adheres to the glass, forming on the opposite side of it a brilliant reflecting surface. An amalgam of bismuth 2 parts, lead and tin 1 each, and mercury 4 parts, is used for silvering the interior of hollow glass globes. This is effected by introducing into the globe a small quantity of the metallic alloy, which is to be melted by immersing the globe in hot water, and then by turning it gradually in all directions, the bright coating will adhere to the inside of the glass. Zinc amalgamated with mercury forms a composition, which increases the electrical energy of glass excited by friction; and it is therefore applied to electrical machines.

Tin constitutes the basis, or enters into the composition of various useful alloys. An extremely important application of this metal, which has been carried to high perfection in modern times, is the coating of other metals. Copper vessels thus covered seem to have been certainly in use among the Romans, and there is reason to believe that they also knew how to apply tin in the same manner to the surface of iron. The process of tinning iron, or making Tin-plate, consists chiefly in dipping sheets of iron into a vessel of melted tin, the surface of which is prevented from oxidation by being covered with melted tallow. The tin thus unites with the opposite surfaces of the iron, forming with it an alloy to a slight depth. Various precautions and manipulations are requisite to ensure the complete success of the operation, and conduct it in the most economical manner, of which ample information may be found in a valuable paper on the manufacture of tin-plate, by Mr. Samuel Parkes.* The process of tinning the interior of copper vessels for culinary purposes is effected on similar principles. The copper surface is first polished, and then coated with sal ammoniac and pitch, to prevent oxidation, and the vessel being heated, the tin finely divided, and also heated, is applied to it, and adheres to its superfices. The composition of Bronze used by the ancients in casting medals, figures in relief, and for other purposes, is not exactly known; and it is probable that different kinds of alloy were used by artists in different countries, and for various purposes. Tin and copper, however, appear to have been the chief, if not the sole constituents of this alloy; and compounds of those metals are still employed for works of an analogous description. Gun-metal and Bell-metal are thus constituted, the proportions of tin and copper varying according to circumstances. Pewter is said to be an alloy of tin and copper, containing 1 part of copper to 20 of tin: but the composition of this substance is extremely variable. Common pewter consists of cheaper materials, being formed of 80 parts of tin and 20 of lead; while the finest pewter has been stated to contain about 12 parts of tin and 1 of antimony, with a small portion of copper. Britannia metal, now frequently used for making teapots, spoons, and other articles, forming a cheap substitute for silver, much resembles the lastmentioned sort of pewter. Its composition has been thus stated: The best block tin 3½ cwt., antimony 28 lb., copper and brass, of each 8 lb. Speculum metal, a brilliant alloy, used for the construction of concave mirrors for reflecting telescopes, is another alloy into the composition of which tin always enters, though its chief constituent is copper. The grand object in the formation of this substance is to obtain a reflecting body which shall yield a single distinct image, have hardness to admit of its being highly polished, and a surface as little as possible liable to become tarnished by air and moisture. Various metallic combinations have been employed for these purposes, by different artists and experimental philosophers, among which it will be sufficient to mention the alloy of 1 part tin and 2 of copper, recommended by Mr. Mudge; and the more complex metal formed of copper 32 parts, tin 15 or 16 parts, and brass, arsenic, and silver, each 1 part.

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* Brande's Lect. on Min. Chem. in Journ. of Science, vol. iv. p. 242.

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* See Journal of Science, vol. viii.; Memoirs of the Manchester Philosophical Society, N. S., vol. iii.

Lead when alloyed with other metals seems to impair their tenacity, while it renders them more fusible. The most useful of its alloys is Type-metal, composed of about 16 parts lead, and 1 antimony and copper; but the proportions, if not the ingredients themselves, differ in different foundries, a good deal of secrecy being observed with respect to the methods of forming this compound. The chief object in the combination must be to obtain complete fusibility, so that when cast the type shall be perfect, forming an exact counterpart of the matrix; and likewise that the letters may be hard enough to wear well, and stand their work firmly, having just so much tenacity as to break rather than bend, when under the application of great force. An alloy of lead and antimony is also used to make plates on which music is engraved.

Copper forms various valuable alloys, the most important of which is Brass, in which it is combined with zinc. This alloy is usually produced by mixing granulated copper with calamine (ore of zinc) and charcoal, and exposing the mixture to a degree of heat sufficient to reduce the ore, and the revived zinc uniting with the copper in a state of fusion, the melted alloy is cast into plates. The proportions of the respective metals employed are variable, constituting different kinds of brass: but it usually contains from 12 to 18 per cent. of zinc, according to Brande; though Dr. Thomson found, in the valuable alloy called Dutch brass, 70 parts of copper, and 30 of zinc. Pinchbeck, Prince Rupert's metal, Dutch gold, Tombac, and Similor, are alloys composed of copper and zinc, the proportion of the latter metal being smaller than in brass, and hence they are formed by the addition of copper to brass. Tutenag is said to be an alloy of copper with zinc and a little iron. In a metallic substance called White Copper, brought from China, Dr. Fyfe found, besides the three metals just mentioned, a large proportion of nickel.

MINERALOGY.

DESTITUTE OF EVERY OTHER CONSIDERATION THAN THE VALUE OF TRUTH IN ALL THE WALKS OF HUMAN WISDOM, MINERALOGY IS ENTITLED TO OUR REGARD. THE ELEMENTS OF VEGETABLE AND ANIMAL EXISTENCE ARE THE OBJECTS OF ITS CONSIDERATION. VIEWING THE ORGANIZATION OF PLANTS AND ANIMALS, WE REFER TO THE PRINCIPLE OF ANIMATION, AS A VISIBLE AND MEDIARY AGENT, BY WHICH OUR THOUGHTS ASCEND TO THE GIVER OF LIFE. BUT WHEN WE BEHOLD INERT MATTER ASSUMING FORMS THE MOST BEAUTIFUL AND REGULAR, OBEYING THE STRICTEST GEOMETRIC LAWS, AND INDICATING THE PRESENCE OF INTELLIGENCE THE MOST AWFUL—WE, AT ONCE, LOOK UP TO HIM, WHO HATH THUS SPOKEN IN HIS HOLINESS, AND WHOSE "HANDS PREPARED THE DRY LAND."

Dr. E. D. Clarke's Lectures on Mineralogy.

MINERALOGY.

The object of this science is to describe the general composition, haracters, varieties, forms, and combinations of mineral bodies. A ineral may be described as a substance destitute of organization and itality, found on the surface of the earth, or imbedded at various epths beneath it, in veins or strata, which are worked for the ex- raction of such substances, by excavations, called mines. Minera- gy may be distinguished from Chemistry, as relating to the forms and roperties of certain bodies as they are presented to us by nature; hile the latter science instructs us how to procure a multitude of tificial products, derived alike from the animal, vegetable, and mineral ngdoms, and to explore their properties, especially as respects their odes of combination. Mineralogy is likewise to be distinguished m Geology, with which, however, it is intimately connected. It is the province of the geologist to investigate the general structure of the earth, and the nature and arrangement of the great masses of which it is composed. The mineralogist, on the other hand, confines his attention to individual portions of unorganized matter, distinguished by peculiar and specific characters. In the study of geology it is of the utmost importance to be enabled to examine the objects of research, *in situ;* and to ascertain their relative connexion and arrangement in the formation of rocks, mountains, plains, subterraneous strata, and, in general, of all the great masses, the assemblage of which constitutes the solid shell, or exterior surface of the terrestrial globe. The nature and properties of minerals may be investigated and ascertained, without any reference to the situations in which they are produced.

Thus connected as Mineralogy is with Chemistry, on the one hand, and with Geology on the other, it displays features sufficiently distinct from those of either; yet, at the same time, the objects of these sciences so far correspond, that a complete knowledge of Mineralogy cannot be obtained without a previous acquaintance with Chemistry, nor can the information which these sciences united afford, relative to the unorganized productions of nature, be applied to a more exalted purpose, than that of aiding our researches concerning Geology.*

Mineral substances may be discriminated from each other by the mode of crystallization or aggregation, and the optical properties depending on their peculiar forms; by their physical characters, as colour, lustre, transparency, hardness, consistency, density, or specific gravity; as also in some cases by their taste or odour, by their re-tions to electro-magnetism, and finally by their chemical constitution. Any or all of these various qualities and affections may be taken into consideration in forming classical arrangements of bodies belonging to the mineral kingdom of nature. Hence a diversity of systems and arrangements have been contrived by various mineralogical writers. But those who have been engaged in such theoretical speculations, have succeeded so indifferently, that a distinguished professor of mineralogy, in his remarks on the state of the science in this country, says, "The value of a method of classification seems to be looked upon as a point not worth discussing, any one method is considered as good or as bad as any other. This opinion, indeed, is openly maintained by some of our best mineralogists. Their labours have been employed solely and exclusively in the crystallographical and chemical analysis of particular species; and I am not aware that any attempt has been made, among us, to establish any proposition including a class of species of minerals, with the exception of Sir David Brewster's optical researches."* But on the continent the case is widely different; a number of mineralogical systems having been published of late years in Germany, France, and Sweden; some of them founded on the chemical constitution of minerals, some on their crystallographical or other physical properties, and others which may be called mixed systems of classification, depending on a combined view of physical and chemical characters. The number, variety, and discrepancies of the systems of mineralogy, which have been recently proposed, abundantly evince the difficulties that attend the subject; and though we should not be inclined to admit that all methods are alike in point of value, yet, it must at least be acknowledged, that various modes of arrangement might be pointed out, the advantages and disadvantages of which would so nearly correspond, that it would be difficult, if not impossible, to decide which had the superiority.

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* The necessity of exact mineralogical knowledge to the geologist has been very justly and forcibly expressed by Mr. Aikin in the introduction to his *Manual of Mineralogy*, published in 1815. He says, "The absolute necessity of extreme accuracy in discriminating one species of mineral from another, is too obvious to require any further remark, if examples were not perpetually presenting themselves of persons very slenderly provided with these rudiments of the science, who yet undertake geological investigations, and with a peremptoriness generally in proportion to their ignorance, challenge the credit of new discoveries, or call in question the observations of their predecessors. It is, indeed, very true that geological speculations are as fascinating to the student as the discrimination of species is generally repulsive; yet it ought to be borne in mind that as all sound scholarship is founded upon grammar, so all sound geology depends primarily on a familiar acquaintance with the distinctive characters of simple minerals."—*Encyc. Metropol. Mixed and Applied Sciences*, vol. iv., *Mineralogy*, p. 465.

But whatever kind of arrangement might be adopted, attention must necessarily be paid both to physical and chemical characters, in rranging and describing the different genera and species into which mineral bodies may be distributed. Crystallographical properties are mong those characteristics of minerals which are of the highest importance; for though some bodies belonging to the mineral kingdom exhibit no traces of crystallization, yet they are comparatively few and inconsiderable; hence the study of crystallography is necessarily connected with that of mineralogy, and the subject is in many respects so important, as to render it deserving of especial consideration; therefore, in addition to the remarks on crystalline forms which may occur in the notices of the several kinds of minerals, some further observations on crystallography will be added to the latter part of this treatise.

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* Whewell on the Recent Progress and Present State of Mineralogy, in eport of British Association for 1832, pp. 324, 325.

The physical characters of minerals require a few preliminary remarks. *Colour* is one of those properties of mineral bodies, which, though frequently serviceable in distinguishing them from each other, is by no means constant; for though there are some minerals which always exhibit the same tints, there are others which display the utmost diversity; so that specimens having an apparent identity of chemical constitution, and, in most respects, of physical character, will yet be found of very different colours. This is especially the case with those mineral bodies which are considered as precious stones, and when cut and polished, used as ornaments. Thus the gem called the sapphire, sometimes exhibits its characteristic sapphirine, or blue colour, and is likewise found purple, red, green, yellow, grey, and white, or perfectly transparent. Topazes are found yellow, pale blue, green, transparent or colourless, and sometimes of a fine red. Garnets occur not only red, but also black and brown. The diamond is seldom entirely free from colour, and some are found blue, pink, dark brown, or yellow. Some minerals, as the opal, exhibit different colours when viewed by transmitted light, from those which appear when seen by reflected light. Yet, notwithstanding these anomalous phenomena, the colour may frequently be employed as a discriminative characteristic of mineral bodies; for though, when considered alone it might afford no certain indication of the nature of a mineral, yet taken in conjunction with other characters, it will be found frequently useful, as enabling us to describe and distinguish mineral substances.

Lustre is one of the external characters of minerals, which is of considerable importance. The principal kinds of lustre are the adamantine, the vitreous, the oily, the resinous, the fatty, the pearly, and the metallic; to which may be added the semi-metallic. The metal- re is peculiar to certain metallic ores, and is always accompan by opacity; and the semi-metallic characterizes various earthy as well as metalliferous minerals. Mineral substances also differ in the degree as well as the kind of lustre which they display. Thus the highest degree of brilliancy is termed splendid, whence we descend through the various grades of shining, glistening, and glimmering, till we arrive at that which is called dull, to be observed in most of those minerals the fracture of which is earthy. This characteristic may also be further modified, and terms employed to denote intermediate degrees of lustre. Thus it may be stated that the lustre of a mineral is strongly or faintly glimmering, passing into glistening, but such distinctions are scarcely necessary, except in describing new-discovered substances. "The different kinds of lustre undoubtedly depend upon optical differences in the surfaces, which differences have not as yet been clearly explained. Professor Breithaupt is in the habit of showing, by the superposition of a number of watch-glasses, that the pearly lustre results from the lamellar structure of a transparent mass. The very curious difference between the optical properties of the surfaces of metals, and of transparent bodies, has been traced on different roads, by Sir David Brewster and by Professor Airy, and both agree in considering the optical properties of the diamond as intermediate between the transparent and the metallic character, though they do not agree in their representation of the peculiar laws which the diamond discloses. When the connexion of these properties with those of other bodies is clearly made out, we shall probably learn more distinctly than we now can, what is the precise distinction of metallic, adamantine, and vitreous lustre."[*]

Transparency is a property which does not belong to all minerals, and in those which possess it, it exists in different degrees. Some minerals are semi-transparent, as carnelian, and certain kinds of obsidian; others are merely translucent, or but little removed from opacity. A few minerals which appear opuque, when examined in the air, become more or less transparent if immersed in water. This is the case with a sort of opal, hence called hydrophane.[†]

Hardness is a very important, because it is a very constant property in most simple minerals. Professor Mohs, of Vienna, has formed a scale of numbers to indicate the degree of this property respectively belonging to any mineral. In this scale the hardness of common talc is 1, of gypsum 2, of calcspar 3, of fluor spar 4, of apatite, or asparagus stone 5, of feldspar 6, of quartz 7, of topaz 8, of corundum 9, and of diamond 10. The hardness of a mineral may be ascertained by trying whether it will scratch another, the relative hardness of which is previously known. Hence, according to the preceding scale, supposing the hardness of a mineral to be indicated by 5½, it must be inferred that it is intermediate between 5 and 6, and therefore that it would scratch apatite, and be scratched by feldspar. Professor Breithaupt, of Freyberg, has extended the numerical scale of Mohs from 10° to 12°, by introducing mica between gypsum and calcspar, and sodalite between apatite aud feldspar, as intermediate degrees; and it is obvious that if it were thought desirable, further distinctions might be made, and the scale might be enlarged. It is an observation of some importance with respect to the hardness of several minerals, that it appears to be different in different parts, and even in different directions. Thus the edges and solid angles of crystals seem to be harder than their faces, and in the diamond serviceable cutting points can only be obtained from natural crystals. The diamond-cutters distinguish the angles of a dodecaedral crystal into hard and soft points, the former consisting of those which are also the angles of the primitive octaedron, and which cannot be split or broken off, but must be ground down with diamond powder; while the low triangular pyramids, which form the other points, may be removed by cleavage. Kyanite affords an example of a mineral, the hardness of which will differ according as it is scratched, along or across the direction of its axis.

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[*] Whewell on Mineralogy, in Rep. of Brit. Assoc. for 1832, p. 327.

[†] From the Greek Ὕδωρ, *water*, and *Φαίνω, to show light.*

Consistency is a property which is intimately connected with hardness, but of a more general nature. A substance may be at the same time very hard and very brittle, or it may be extremely soft, and at the same time tough or tenacious. Thus euclase and anthophyllite are hard bodies, but easily frangible, or broken by a blow; while asbestus or amianthus, which are very soft and flexible minerals, are at the same time very tenacious, so that fibres of these substances may be twisted into threads, and woven to make cloth.

Density, or *Specific Gravity*, is one of the properties of mineral bodies deserving of attention, as furnishing the means of discriminating them from each other. The nature of this property of matter with regard to substances in general, has been amply noticed in the preceding volume of this work, in which, likewise, the modes of ascertaining the specific gravity of bodies, has been described and illustrated.[*] Much attention has been paid to specific gravity, as a characteristic property of minerals, by Professors Mohs and Breithaupt, who have determined most minutely the value of this element for very extensive series of minerals. Beudant has discovered that large crystals, and especially bacillary masses, are inferior in specific gravity to small crystals; and he therefore recommends the pulverization of minerals previously to trials of their specific gravity, in order to obviate the uncertainty that might arise from these differences in the mode of aggregation. Magnus found that garnet and similar minerals, when melted, and again solidified in a glassy but uncrystalline state, have their density diminished by the operation; the Greenland garnet, for instance, when thus treated, had its specific gravity reduced from 3.9 to 3.05.[†]

Taste and *Odour* are sensible qualities of minerals, which cannot be very extensively applied to practical purposes. Taste is chiefly confined to saline minerals, and is sufficiently obvious in most cases where it exists, as in rock-salt (Chloride of Sodium), and alum (Sulphate of Alumine). Some minerals are distinguished by a peculiarly disagreeable smell, as is the case with a particular kind of limestone, which is hence called stinkstone, or swinestone.

Electro-magnetism, or *Electricity*, manifests its influence in some minerals, by the production of a phosphorescent light, when they are subjected to collision or friction; and others, by friction or the application of heat, may be made to attract light bodies, in the same manner as excited glass or sealingwax.[‡]

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[*] Book of Science, part i. pp. 144—151.

[†] Whewell on Mineralogy, in Rep. of Brit. Assoc. for 1832, p. 326.

[‡] The effect of heat and friction in exciting phosphorescence or electric light, has been noticed in the Book of Science, part i. pp. 346, 347; 2d ed. pp. 354, 355. The development of electric attraction by heat or friction, has been observed and made the subject of experiments by Hauy, and other mineralogists. The electric property of the tourmaline long since attracted attention, and among the minerals capable in some degree of similar excitation, may be mentioned boracite, topaz, axinite, mesotype, prehnite, calamine, and sphene or titanite. See *Encyclop. Metrop.*, *Mixed Sciences*, vol. ii., *Electricity*, pp. 131—134.

There are many terms denoting properties or appearances of mineral bodies which are of frequent occurrence in treating concerning them, and may therefore be briefly explained. Minerals are said to be *adhesive* when the newly fractured surface adheres if applied to the tongue, as is the case with slate. Those which may be divided into thin plates, are termed *lamellar* minerals. Crystals, the length of which greatly exceeds their other dimensions, are called *bacillary* crystals, and when they are very much attenuated, they are termed *capillary*, and if they diverge from a common centre *scopeform* fibres. Irregular globular bodies are styled *nodules*, or *nodular* masses, and those which have no symmetrical form, are called *amorphous*. *Specular* means smooth, shining, mirror-like; *tabular*, approaching to flatness; and *vesicular*, sponge-like, or full of holes or vesicles.

Minerals are properly definite compounds, in various states of complication, of those elementary bodies with which chemistry has made us acquainted, except in a few instances; some bodies, as gold and carbon, being presented to us by nature in a pure and uncombined form. Among compound mineral bodies there are some, however, which appear to be simply aggregated, or to consist merely of mingled masses, while by far the greater number are chemical compounds. When minerals are simply aggregated, as for instance, when gold is found in limestone, the separation of the metal may be effected by the mechanical operations of pounding and washing; but in the case of chemical compounds, as sulphur and copper (copper pyrites), or oxide of tin, called wood tin, the separation of the metal from the sulphur in the first case, and from the oxygen in the second, can only be effected by chemical processes, the nature of which has been already described in the Treatise on Metallurgy. Among the ultimate or constituent elements of minerals may be mentioned,

Oxygen
Hydrogen
Chlorine
Nitrogen
Sulphur
Selenium
Carbon
Phosphorus
Water

Potash
Soda
Lithia
Barytes
Strontia
Lime
Magnesia
Alumine
Zircon

Glucine
Yttria
Thorina
Ammonia.

Acids.

Carbonic Acid
Phosphoric A.
Fluoric A.
Sulphuric A.
Muriatic A.
Nitric A.
Boracic A.
Tungstic A.
Chromic A.
Molybdic A.
Telluric A.
Arsenic A.
Titanic A.
Columbic A.
Antimonic A.
Vanadic A.
Silicic A.
Succinic A.
Mellitic A.

Metals.

Platina
Gold
Silver
Mercury
Palladium
Rhodium
Iridium
Osmium
Copper
Nickel
Iron
Tin
Zinc
Cadmium
Tungsten
Bismuth
Cobalt
Manganese
Molybdena
Uranium
Cerium
Antimony
Chromium
Columbium
Arsenic
Titanium
Tellurium
Vanadium.

CLASSIFICATION OF MINERALS.

The earlier systematic writers on mineralogy in general arranged mineral substances in four classes, namely, Earths, Salts, Bitumens, and Metals; subdividing these into orders depending on their textures or other physical properties. Such systems were superseded in Germany by that of Werner, founded on the joint consideration of chemical and external characters; and the arrangement of that distinguished philosopher was, with some modifications, for a long time generally adopted by mineralogists in this country. Werner and his followers employed the division of classes above stated, only substituting the term Inflammables or Combustibles for that of Bitumens; but the sections or subdivisions were variously altered and improved. In France a system was proposed by Hauy, founded on crystallization, as the most distinguishing character of minerals. He defined a mineral species to consist of individual bodies similar in their composition, and with crystalline forms also similar. Some minerals, however, are not crystallized, and such he distributed according to their chemical composition. "The definition which seems to be recognised in the crystallometrical school of more modern times is, *the same primary form with the same fundamental angles of cleavage, combined with an approximate identity of chemical and physical characters.*"*

Both the system of Hauy and the more modern doctrine are founded on a presumed relation between chemical composition and crystalline form, examples of which are too numerous to admit of the least question, but concerning the nature and extent of the relation we are not yet qualified by any means to decide; and hence arises a manifest source of imperfection and discrepancy in the mineralogical arrangements derived from it. Observations that have been made of the analogy of form between bodies varying in composition led to the assumption of the principle of Isomorphism, or Plesiomorphism; which, as being connected with crystallization, will be further noticed in treating of that subject.

Professor Berzelius has constructed an arrangement of mineral bodies, founded on their relative electro-positive and electro-negative properties. This system, since it was first proposed in 1816, has been considerably modified, especially in consequence of the discoveries that have been made relative to isomorphism; and though still necessarily imperfect, it may be regarded as the nearest approximation yet obtained towards a regular and consistent classification of mineral substances.

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* Whewell on Mineralogy, in Rep. of Brit. Association for 1832, p. 350.

"The order established by the *electro-chemical* relation of bodies is supposed to be generally preserved in all their combinations. Thus, if A be *electro-negative* in respect of B and of C, B will generally be electro-negative in relation to C; but this appears not to be universally so; and sometimes one electro-negative body is found combined with two or more bases, and sometimes two acids are combined with a single base. If, says Berzelius, with these theoretic notions in our mind, we look through the productions of the mineral kingdom, the apparently confused combinations which minerals present will be immediately pervaded by regularity and order. We perceive an extensive class of minerals into which silex enters as a constituent, assuming the character of salts, either simple, double, triple, or quadruple; and with various excesses of the *acid* or the *base*. In the same manner we perceive the oxides of titanium, of tellurium, and of other metals, performing the functions of acids, and thus reducing the whole series of minerals to one uniform system of classification; and the doctrine of definite proportions introduced within a few years into chemistry, might, if we could fully avail ourselves of its aid, be said to confer on this system of mineralogical classification a degree of almost mathematical precision. But in consequence of the difficulty of ascertaining the proportions of the actual ingredients of minerals, and the still greater difficulty of distinguishing those which are essential to the species analyzed, we are not yet enabled to confer on a chemical classification all the advantages offered by the improved doctrines of chemistry."*

Professor Whewell has remarked that though we do not at present possess any system of arrangement on strictly chemical principles, bringing together in all cases, the substances which most resemble each other in external properties, yet the arrangements recently proposed, by Berzelius and others, may be regarded as approaching to such a perfect system, whether they be founded upon external characters, or on chemical principles. "The new system of Berzelius, or that of Beudant, or indeed any of the new chemical systems, would produce a grouping of substances which would at once be recognised as far more natural than that of Hauy or Phillips. The last system of Berzelius has been adopted in the arrangement of the minerals of the British Museum, in their new apartment, under the intelligent and industrious superintendence of Mr. König; and every one will probably be struck by the evidence which the aspect of the collection offers of the advantage of this over the ancient mode of arrangement."*

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* Encycl. Metrop.—Mixed Sciences, vol. iv., Mineralogy, p. 466.

As this great national museum is readily accessible to all who reside in or visit the metropolis, an excellent opportunity is presented for studying mineralogy by means of a copious and well-selected cabinet of minerals; and this circumstance would afford an additional motive, if any were wanting, for adopting in the ensuing descriptive notices of the principal minerals, the electro-chemical classification or system of Berzelius.

Table of Mineral Classes.

- Electro-positive Metals and their Alloys.
- Electro-negative Bodies and their Combinations.
    - Carbon and Carburets.
    - Selenion and Seleniurets.
    - Sulphur and Sulphurets.
- Oxides of Electro-positive metals.
- Oxides of Electro-negative Bodies, and their Combinations.
    - Alumina and Aluminates.
    - Silicic Acid and Silicates.
        - *a*. Silicates with simple bases.
        - *b*. Silicates with compound bases.
    - Titanic Acid and Titanates.
    - Columbic Acid and Columbates.
    - Antimonic Acid and Antimoniates.
    - Scheelic Acid and Scheelates, or Tungstates.
    - Molybdic Acid and Molybdates.
    - Chromic Acid and Chromates.
    - Vanadic Acid and Vanadiates.
    - Boracic Acid and Borates.
    - Carbonic Acid and Carbonates.
    - Arsenious Acid and Arseniates.
    - Phosphoric Acid and Phosphates.

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* Report of Brit. Assoc. for 1832, p. 360.

Nitric Acid and Nitrates.
Sulphuric Acid and Sulphates.
Fluorides and Fluates.
Chlorides.
Organico-chemical Bodies, or Minerals derived from Organized Matter.
Salts.
Resins.
Bitumens.
Coals.

ELECTRO-POSITIVE NATIVE METALS.

Iron, though one of the most common of the metallic bodies, is not often found in the native state, in consequence of the powerful tendency which it possesses to combine with oxygen, sulphur, and other substances. Most of the existing specimens of native iron are supposed to have derived their origin from meteoric stones; though this metal is said to have occurred in the state of pure iron ore, massive, and in leaves of a grey colour, having a fracture like that of steel, and some degree of malleability. Some notice of meteoric stones will be found in another part of this volume; but besides those masses of ferruginous matter, undoubtedly of aërial origin, large blocks of iron in which the metal exists in various degrees of purity, have been discovered in different parts of the world; and though these probably have been produced in the same manner with the acknowledged aërolites, yet since evidence is wanting as to the source whence they were derived, some account of them may here be added. Among these blocks of iron may be mentioned one found at Ellenbogen in Bohemia; the large mass discovered by Professor Pallas, on the top of a hill, between Abakansk and Belskoi Ostrog, on the banks of the Jenesei, in Siberia, which originally weighed about 1680 pounds; a mass found in Southern Africa, and now in the cabinet of Haarlem, in Holland, weighing about 250 pounds; an immense mass of native iron from Otumpà, in the Gran Chaco Gualamba, in South America, described by Don Rubin de Celis, who estimated its weight at fifteen tons; a mass of iron from Atacama, resembling the Siberian iron; a large mass of iron preserved at Aix-la-Chapelle; two large blocks on a hill in the country of the Esquimaux, near Davis's Straits, pieces of which the people use for making the rude blades of their knives and harpoons; a mass of iron weighing 103 pounds, found in September, 1829, near the castle of Bohumiltitz, in the circle of Prachin, in Bohemia; and one found recently at Magdeburg. Specimens of the iron ores just mentioned, are preserved in the British Museum, with the exception of that discovered at Bohumiltitz. Such of these masses as have been analyzed, have in general been found to consist principally of iron, alloyed with nickel, but the Magdeburg block, according to the analysis of Professor Stromeyer, contains, besides iron and nickel, cobalt, copper, molybdena, and arsenic; and the Bohumiltitz mass appears to contain, with iron and nickel, small quantities of plumbago and sulphur. Native iron, not meteoric, is said to have been found about 1823, in the mountain of Canaan, in the state of Connecticut, North America, forming a thin stratum, or vein, in a mass of mica-slate. It was uncombined with nickel, and quite malleable.

Native Copper is usually found unalloyed, except with small portions of iron and gold. It exhibits a great variety of beautiful forms, besides those of common crystals. Native copper appears of a brighter or darker colour, as it is more or less tarnished, and occurs sometimes in considerable masses, one of which, found by Mr. Hearne, in the country round Hudson's Bay, North America, is described by that gentleman in his journal. Some specimens are foliated, some branching, others in the forms of octaedral, cubic, prismatic, or other crystals; and this metal sometimes displays arborescent, and sometimes fibrous or filiform figures, as represented in the margin.

Bismuth is found native, massive, disseminated, and arborescent, imbedded in jasper or other minerals. When in the massive state its fresh fracture usually presents changeable colours like some silks, or the plumage of a pigeon's neck. It is occasionally found crystallised in octaedrous, or long, double, triedral pyramids, and tabulated; often striated.

The existence of *Lead* in the native state is somewhat problematical. Mr. Rathkie is said to have discovered it in the island of Madeira, but the lead there found is supposed to have been of volcanic origin; and the occurrence of native lead in lava has been observed elsewhere. At the British Museum may be seen a medal, cast in lead, ejected from the crater of Mount Vesuvius in 1631.

Silver is found more frequently pure, or in the state of alloy, than most other metals; but it is most plentiful in the state of native silver. The metal is occasionally found in immense masses; the silver-mines of Kongsberg, Norway, formerly afforded specimens, weighing from 100 to 150 pounds; and in the mine called Nye Forhaabning, one was raised 560 pounds in weight, which is still preserved in the royal cabinet at Copenhagen. Specimens of native silver exhibit a diversity of beautiful forms, such as arborescent, branching, foliated, and moss-like, or in delicate curls like cotton threads. It is also found tooth-shaped, wire-shaped, and sometimes canaliculate and serrated. It likewise occurs imbedded in calcareous spar, in prisms crossing each other in all directions.

Mercury sometimes occurs native in globules, disseminated in coarse sandstone, and other substances. Crystallized cinnabar, or Sulphuret of Mercury, is found occasionally sprinkled with globules of metallic mercury. Native amalgams of the metal with silver occur both in the semifluid and solid states. The hydrarguret of silver crystallizes in perfect and modified rhombic dodecaedrous and other figures. The plastic nature of this amalgam is taken advantage of by the Mexican miners to mould figures and ornaments of this substance, specimens of which may be seen at the British Museum.

Gold is found either in a state of purity, or alloyed with a few other metals, and generally in the latter state. It occurs in foliations upon quartz, associated with other substances; but the great bulk of this precious metal in circulation, is principally procured from alluvial

strata, where it is met with in masses of various sizes. Pure gold occurs either massive, in detached crystals, as grains in the state of gold dust, or interspersed in brown ironstone, in quartz with needle ore, in dendritic or arborescent crystals, and in moss-like masses consisting of delicate interwoven fibres, as in the marginal figure. The alloys of gold are found crystallized in minute cubes and octaedrons, variously aggregated in reticular plates and other forms.

Auriferous Silver, or *Electrum*, is an alloy of a yellowish-white colour, containing gold in various proportions.

Platina occurs in small grains, very heavy, and of a silvery-white lustre. These grains are found in the alluvial strata. With platina are intermixed other metallic bodies, as the alloy of *Iridium* and *Osmium*, in shining foliated grains. *Palladium* is found in delicate scaly grains, of a lead colour, alloyed with platina. *Rhodium* is a white metal, which, with platina, iridium, iron, &c., forms a black alloy.

ELECTRO-NEGATIVE METALLIC AND METALLOIDAL SUBSTANCES, AND THEIR NON-OXIDIZED COMBINATIONS.

Tellurium and Tellurets.

Native Tellurium is a mineral generally of a white colour with a metallic lustre, which occurs massive, fine-grained, and disseminated, in the mines of Transylvania. Graphic tellurium occurs of a greyish colour, with a metallic lustre, sometimes tarnished, exhibiting delicate tetraedral and hexaedral prisms, aggregated or interwoven on the surfaces of other minerals, so as to have some resemblance to Arabic or Hebrew characters. This mineral contains a portion of gold, as also does the yellow tellurium. Black tellurium contains lead.

Native Antimony is found in the mines of Dauphine. It has a white colour like tin, and a granular and foliated fracture: it occurs massive rarely distinctly crystallized. Antimonial silver, or stibiuret of silver, is found in the Hartz mountains, of a bright white colour, massive, and crystallized in cubes or striated. Antimony is also found alloyed with other metals, as nickel and lead.

Arsenic and Arseniurets.

Native Arsenic is much the colour of tin, but soon becomes tarnished, it exhibits reniform and botryoidal figures. Arseniuret of Nickel, commonly called Kupfer-nickel, or copper nickel, has the colour of tarnished copper. Arseniuret of Cobalt comprises the mineral called grey cobalt, from its steel-grey colour. Arseniuret of Bismuth is found in small brownish globules at Schneeberg, in Saxony.

Carbon and Carburets.

This is a mineral which exhibits a great dissimilarity of form and appearance in different states or modes of aggregation. Scarcely any substances can be more unlike in their external characters than the diamond and charcoal, though chemical analysis seems to demonstrate a perfect analogy of composition. Among the minerals which are considered as varieties of pure carbon are diamond, anthracite, and graphite, or plumbago.

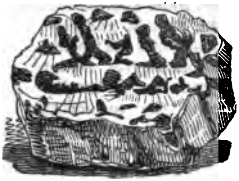
The *Diamond* exhibits several crystalline forms, as the primitive regular octaedron; the same with solid angles truncated; with edges truncated, forming the passage into the rhombic dodecaedron; varieties of the latter, giving rise to the hexaedral, prismatic, and tetraedral forms; cubes with truncated and bevilled edges; and hemitropic crystals or macles. This gem exhibits various colours; some having a brownish or greenish tint, others are yellow, and there are blue, pink, rose-red, and dark brown diamonds: but the latter are very rare. Diamonds of a large size are of very unusual occurrence. Among the most remarkable may be mentioned, the large diamond in the imperial sceptre of Russia, which was purchased by Catherine II. for the sum of 90,000*l.* paid down, and an annuity of 4000*l.* to the seller; its weight is 193 carats, and its size nearly that of a pigeon's egg. This gem is considerably exceeded in weight and dimensions by one which belongs to the Rajah of Mattan, in the island of Borneo, where it was found about a hundred years ago. In shape it resembles an egg, with an indentation near the smaller end. It is said to be a stone of the finest water: its weight is 367 carats, or 2 ounces, 169.87 grains Troy. A Dutch governor of Batavia, wishing to purchase this diamond, offered to the Rajah, in exchange, 150,000 dollars, two large brigs of war, with their guns and ammunition, together with other pieces of cannon, and a quantity of powder and shot; but the Rajah refused to part with the gem, to which the Malays attributed the power of curing diseases, and the possession of other miraculous properties.

Anthracite, or *Kohlenblende*, is a carbonaceous mineral, one variety of which is called Kilkenny coal. Anthracite has a semi-metallic lustre, and a conchoidal fracture, and is sometimes slaty, and occasionally columnar. It burns like charcoal, without flame or smoke; whence in Scotland it is called blind coal.

Graphite, or *Plumbago*, is the well-known substance commonly called black-lead. It is found in England, Scotland, France, Spain, Germany, and other countries; but that variety which is most useful, for making black-lead pencils, is procured from a mine at Borrowdale, in Cumberland. It is said to occur in large, roundish masses, imbedded in a mountain of argillaceous schistus, traversed by veins of quartz.

Selenion and Seleniurets.

Selenion appears to be a substance but sparingly distributed in the mineral kingdom. Among its compounds may be noticed the mineral called *Eukairite*, a *Seleniuret of Silver and Copper*; the *Seleniurets of Lead and of Copper*, which are the products of Swedish mines; and the combination of *Selenion with Sulphur*, occurring in the volcanic regions of Italy. Specimens of these minerals are in the British Museum; one



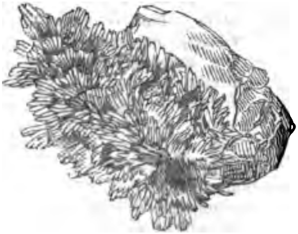
of which, the Eukairite, is exhibited in the annexed figure.

Besides these may be mentioned, the *Seleniuret of Bismuth and Tellurium*, that of *Lead and Cobalt*, the *Cupriferous Seleniuret of Lead*, the *Seleniuret of Lead and Mercury*, and the *Riolite* and *Culebrite*, which are seleniurets of zinc with sulphur and mercury.

Sulphur and Sulphurets.

a. Single Sulphurets.

Native Sulphur occurs in beds of gypsum or selenite, sulphate of strontian, and also, though more rarely, in the veins of primitive rocks. It is found in the mountains of South America, in the Apennines of Piedmont, in the glaciers of Mont Blanc, in Spain, Hungary, Poland, and Siberia. Sulphur occurs crystallized, massive, and stalactitic. It appears in some warm springs in such quantities as to form a deposit when the water is cooled in contact with air. This mineral is often found sublimed, near the craters of volcanoes, as in Italy, Sicily, and South America. Sulphur crystallizes in acute octaedrons, the common base of the two pyramids being a rhomboid: also spongeous and granular, and sometimes forming tufted or branching crystals. (See marginal fig.)

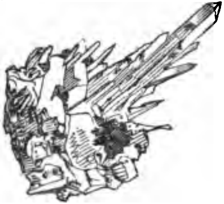


The metallic sulphurets are numerous, constituting a large proportion of the ores from which metals are obtained for economical purposes.

Sulphuret of Manganese, or *Manganese Blende*, is found at Nagyag, in Transylvania, in the mines of Cornwall, and in Peru.

Sulphuret of Zinc, or *Blende*, is usually called by the English miners

Black Jack. The colour of this mineral varies, some specimens being yellow, some brown, and others black. The first is generally the most pure, the others containing iron, silica, and water, as well as zinc and sulphur. One variety of blende when scratched gives out a phosphoric light. The fibrous blende of Przbram, in Bohemia, contains cadmium; and the testaceous or schaalen blende, which has been found at Geroldseck, in the Brisgau, is a sulphuret of zinc with iron and a portion of lead. This mineral occurs massive, and in various forms, as octaedrons, tetraedrons, and dodecaedrons, the primitive crystal being a rhomboidal dodecaedron. Some specimens exhibit spicular crystals, as in the marginal figure.



Sulphuret of Iron, or *Pyrites*, is among the most abundant mineral products in various parts of the world. Large crystals of this substance have been met with in the sepulchres of the Incas of Peru, and they are supposed to have been used as mirrors. Nodules or globular masses are sometimes found in chalk. Its primitive form is the cube; but it occurs variously crystallized, as in the annexed figure. Radiated pyrites (a variety frequently including the lenticular or cockscomb, and the globular pyrites) is very liable to spontaneous decomposition and inflammation, sometimes producing mischievous consequences in mineralogical cabinets. Magnetic pyrites occurs massive. foliated, and crystallized in hexaedra, prisms. Pyrites exhibits a metallic appearance, much resembling brass or pinchbeck.

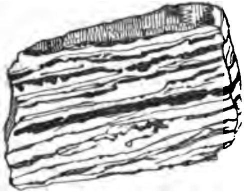
Sulphuret of Cobalt is seldom found crystallized, occurring massive and disseminated.

Its colour is pale steel grey, when tarnished reddish; and it yields a sulphureous vapour when heated. The mines of Tunaberg and Bastnaes, in Sweden, afford cobalt pyrites.

Sulphuret of Nickel, formerly supposed to be native nickel, till its composition was ascertained by Arfvedson, occurs in the capillary form, or that of long, wire-shaped crystals, of a brass-yellow tint, tarnished.

Sulphuret of Copper is the most common ore of that metal, including some varieties. It is found in several forms as compact, foliated or crystallized, the primitive form being an acute octaedron, with a square base. (See marginal figure.) One variety is the malleable copper ore, peculiar to Siberia: the colour said to be a shining steel-grey. The sulphurets, called yellow copper and copper pyrites, contain much iron, as well as copper and sulphur. Variegated or peacock copper ore, which is of this kind, exhibits fine iridescent colours. Among the sulphurets of copper may be reckoned the secondary fossils, styled Frankenberg corn-ears, which are found in bituminous marl-slate, at Frankenberg, in Hesse; and are chiefly composed of vitreous and grey copper. Tennantite, found in copper-mines near Redruth, in Cornwall, appears to differ from grey copper ore, in containing more sulphur and less iron, and in possessing greater hardness.

Sulphuret of Lead, or *Galena*, is the most important, as well as the most common of the ores of this metal, constituting the principal source from which it is obtained. It usually contains silver, in addition to lead and sulphur. It occurs in extensive beds and veins, in primitive and secondary rocks, most abundantly in argillaceous schist and secondary limestone; and it is accompanied by the ores of zinc, copper, iron, and silver; and by quartz, sulphate of barytes, carbonate of lime, and fluoride of calcium (fluor spar). Much of this ore is obtained from the mines of Derbyshire. It is found massive, or crystallized in cubes and regular octaedrons. The peacock lead ore of the

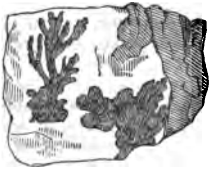


miners displays varying purple tints, like a dove's or peacock's neck. A compact and specular variety is styled by the Derbyshire miners "Slickenside." Blue lead ore, crystallized in hexagonal prisms, is found at Huelgoit, in Bretagné. Antimoniated galena, of a tin-white colour, aggregated crystals, contains, besides lead and sulphur, a large portion of antimony.

Sulphuret of Bismuth, or *Bismuth Glance*, occurs massive, or in delicate acicular crystals. Cupreous bismuth ore is a sulphuret of bismuth and copper, which is found massive and disseminated. Needle ore, a sulphuret of bismuth, lead and copper, which derives its appellation from its wire-like appearance, occurs imbedded in quartz.

Sulphuret of Tin, or *Tin Pyrites*, also called bell-metal ore, from its colour, is a compound of sulphur, tin, and copper, with a small portion of iron.

Sulphuret of Mercury exhibits some diversity of colour and form. There are two varieties, cinnabar, and hepatic mercurial ore, the former of which is divided by Werner into the dark red cinnabar, the colour of which approaches that of cochineal; and the bright red, or native vermilion. The hepatic mercurial ore, or liver ore, is a mixture of cinnabar with bituminous and earthy matter, compact and slaty, found in the mines of Idria. Coral ore is of the same nature, with petrifactions. This sulphuret occurs disseminated and superficial, forming arborescent figures on clay-slate, &c. (See marginal figure.)



Sulphuret of Silver, or *Vitreous Silver Ore*, occurs massive, or crystallized in cubes, octaedrons, and dodecaedrons, besides other forms. Black silver ore is a pulverulent variety of this sulphuret, having a scoriaceous, sooty appearance; sometimes massive, or coating native silver.

Sulphuret of Antimony, or *Grey Antimony*, occurs compact, foliated, radiated, or plumose; composed of downy fibres, disposed in nests, or

fascicular crystals. (See marginal figure.) Some varieties exhibit a fine iridiscent blue, yellow, and red tarnish.

Sulphuret of Arsenic, when it contains a large proportion of sulphur, constitutes the mineral called orpiment, characterized by its bright yellow colour; with a larger proportion of sulphur, arsenic forms realgar, or red orpiment. The latter is said to occur chiefly in primitive rocks, but the yellow orpiment in the secondary or floetz rocks of Werner; and both are found near volcanos. These minerals are sometimes massive, or lamellated; and occasionally, but more rarely, crystallized.

Sulphuret of Molybdena is a sectile, shining substance, resembling plumbago, and generally massive or laminated; rarely crystallized. It is found in Sweden, Bohemia, and near Mont Blanc, disseminated in a grey granite. It has also been met with in Cornwall, and in Inverness-shire, North Britain.

b. Composite Sulphurets.

Sulphuret of Arsenic and Iron, Arsenical Pyrites, or *Mispickel,* occurs principally in veins in primitive mountains, and is common in the copper-mines of Cornwall. It is often iridescent. Some varieties are argentiferous, and exhibit a tarnished silver hue. *Glance Cobalt* is an arsenio-sulphuret of cobalt, which is found massive, and crystallized in cubes, octaedrons, dodecaedrons, and various other derivative forms.

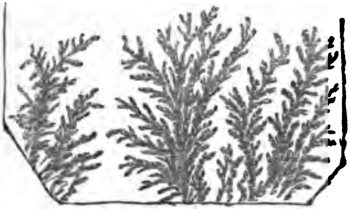
Among the composite sulphur salts may likewise be mentioned the *Bournonite* (so called from its discoverer, Count Bournon), which is a sulphuret of lead, antimony, and copper; crystallized in tetraedral prisms, variously modified.

Red or *Ruby Silver Ore* is distinguished into two kinds, the dark red and the light red, both crystallizing in hexaedral prisms; but the former is a sulphuret of silver and antimony, and the latter a sulphuret of silver and arsenic: there are also other varieties.

Grey Copper Ore, or *Fahlerz*, is a double sulphur salt, of copper and antimony.

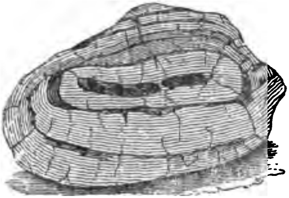
OXIDES OF THE ELECTRO-POSITIVE METALS.

The *Oxides of Manganese* occur in considerable variety, and are very generally disseminated, being found in Great Britain, and several other European countries. Fibrous Grey Manganese crystallizes in delicate acicular crystals, and other varieties are radiated, foliated, or compact, the latter sometimes in botryoidal masses. Earthy Grey Manganese is much used in the preparation of oxygen gas. Fibrous Black Manganese is found dendritic, on the surface of stone, or indurated marl. (See marginal figure.) Wad is often ochreous, of a brown or black colour. Sulphuretted Oxide of Manganese, which resembles the grey oxide, is found with the ores of tellurium, at Nagyag, in Transylvania. Franklinite is an oxide of manganese with zinc and iron.



The *Oxides of Iron* are extremely numerous. Specular Oxide, or Iron Glance, found in the Isle of Elba, is remarkable for its beautiful iridescent or changeable colours; and specimens from Stromboli and Vesuvius occur in large lamellar crystals, often imbedded in lava, looking like polished steel. Iron Mica is found in delicate, bright, hexaedral, tabular crystals, of an iron-grey colour. Red Iron Ore includes the varieties of compact red ironstone, and red hæmatite, the latter in large masses, uniform, or mammillated. Magnetic Ironstone, or Oxidulated Iron, is very common, both massive and crystallized, in octaedrons. Wootz, or Indian Steel, is obtained from an ore of this kind, found in the East Indies. Hydrous Oxide of Iron, or Brown

Ironstone, occurs in several varieties, as the Micaceous, called Goethite, forming transparent tables, of a blood-red hue; that in fine scales, lining the cells or vesicles found in lava; in the state of a dark brown powder, used by the Booshuanas of South Africa, as hair-powder; the fibrous brown ironstone, or brown hæmatite, in silky fibres, or zoned, attached to the roofs or walls of caverns; the compact brown iron ore, and brown ochre. Argillaceous, or Clay Ironstone, occurs in nodules, reniform masses, &c. (see marginal figure), and some specimens exhibit impressions of ferns and other vegetables.



Among the *Oxides of Copper* are the native protoxide, or Ruby Copper Ore, which occurs massive and crystallized in octaedrons and other figures: and there is a variety found in Germany in beautiful bright red capillary crystals. The Tile Ore, a compact earthy variety, is a mixture of ruby copper and brown iron ochre.

Oxide of Lead, or *Native Minium*, supposed to be produced from the decomposition of galena, has been found in the lead-mines of Yorkshire, and on the continent of Europe. Yellow oxide has been obtained from Siberia; and an ash-grey variety, coating galena, is said to have occurred in North Wales. Plombgomme, so called from its appearance, is a compound of lead with oxygen, alumine, and water, of a shining yellow colour, and mammillated.

Oxide of Bismuth, or *Bismuth Ochre*, is a light yellowish-grey or greenish mineral, earthy and friable, which is found in Saxony and Bohemia.

Oxide of Zinc, called red oxide, from its colour, occurs disseminated in groups, indeterminately crystallized, or of a lamellar structure, in iron-mines in New Jersey, N. A.

Oxides of Cobalt.—The Black, Brown, and Yellow Cobalt Ochres, appear to be hydrates, or combinations of water with the oxides of cobalt and manganese, frequently mixed with oxide of iron.

Oxide of Uranium, called *Uran Ochre*, exhibits various shades of yellow. Pechblende is a ferriferous oxide of uranium, containing also lead, copper, and other substances.

Oxide of Tin includes common tin ore and wood-tin. The former occurs massive, variously crystallized, and disseminated in granite; it also forms delicate capillary crystals. Wood-tin has been found only in Cornwall and in Mexico; its structure, in general, is fibrous, having the appearance of wood, but extremely heavy. A variety called in Cornwall toad's eye wood-tin, exhibits globular concretions of radiating fibres disposed concentrically in brown and yellow colours.

OXIDES AND OXACIDS OF ELECTRO-NEGATIVE SUBSTANCES, WITH THEIR COMBINATIONS.

Alumina and Aluminates.

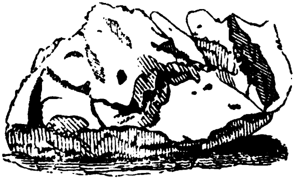
The *Oxide of Aluminum,* which constitutes in its pure state aluminous or argillaceous earth, sometimes occurs alone in a crystallized form, and sometimes acts the part of an acid, entering into combination with the oxides of other bodies. Among the varieties of native Alumina, are the Perfect Corundum, which is found of different colours. The blue kind is the gem called the Oriental Sapphire, the purple the Oriental Amethyst, the yellow the Oriental Topaz or Chrysolite, the green the Oriental Emerald, and the red the Oriental Ruby. The Adamantine Spar, or Imperfect Corundum, and Emery, are also chiefly composed of alumina, containing only very inconsiderable portions of Silica and Oxide of Iron. Fibrolite (called, by Lucas, Bournonite), according to an analysis of Chenevix, consists principally of alumina and silica. The Indianite of Count Bournon is a granular mineral from the Carnatic, containing specks of Hornblende, and it is one of the matrices of the common corundum. Diaspore and Gibbesite are hydrates of alumina.

The *Aluminate of Magnesia* occurs in the Spinel or Balas Ruby, consisting of red octaedral crystals, and there is a blue kind of spinel found in Sudermania, in Sweden. Ceylonite or Pleonaste, which has been reckoned a variety of the spinel, according to Ekeberg, contains iron as well as alumina and magnesia. The Automalite or Gahnite, found in Sweden, and in New Jersey, N. A., has been termed the Zinc Spinel, being a combination of alumina with oxide of zinc. Plombgomme, already mentioned, is a hydrous aluminate of lead.

Silica and Silicates.

The *Oxide* or *Acid of Silicon*, and its combinations with the oxides of other bodies, form by much the most numerous division of mineral substances. In previous arrangements the siliceous minerals have in general been considered as constituting so many distinct species, but they may with more propriety be regarded as merely varieties, whose peculiar external characters are respectively derived from the admixture of extraneous substances, or from other circumstances connected with their formation.

Rock-crystal, which is composed of pure siliceous earth, crystallizes in various forms, the primitive crystal, which is of rare occurrence, being an obtuse rhomboid. Sometimes it appears in hexaedral pyramids, with acicular diverging fibres, as in the marginal figure. Very fine specimens, and some of extraordinary size, are found in Madagascar, and among the Alps. At the British Museum are rock-crystals more than a foot in length. Among the accidental varieties may be mentioned Cairngorm stones, from the mountain of Cairngorm, in Scotland, also called, from their colours, brown, yellow, and smoky topazes. Of the same nature, but colourless, are Bristol diamonds, found on St. Vincent's Rocks, near the Hot Wells. Amethyst Quartz is tinged with a little iron and manganese. Rose Quartz derives its roseate hue from Manganese. Red Quartz, in small crystals, coloured by iron, has obtained the name of Hyacinth of Compostella. Other varieties are fibrous quartz; flexible sandstone, found in Brazil, and at Mount St. Gothard, in Switzerland; stalagmitic quartz, or quartz-sinter, including the siliceous concretions formed by deposition from the hot springs of Geyser, in Iceland; pearl-sinter, or fiorite, from the hill of Santa Fiora, in Tuscany, and from the Isle of Ischia; ceraunian-sinter, or fulgurite, supposed to have been formed by the action of lightning; iron-flint, or ferruginous quartz, containing small quantities of iron; and hyalite, which contains water combined with silica. Prase or Green Quartz, contains Actinolite. Avanturine is a beautiful kind of quartz, of a rich brown colour, exhibiting interspersed glittering particles, either from the presence of minute scales of mica, or from the occurrence of abundance of small fissures, which cause numerous reflections of the rays of light; and the cat's-eye, chiefly from Ceylon, displays an opalescent lustre, owing to almost invisible fibres of Amianthus imbedded in the quartz. Hornstone is of two kinds, called conchoidal and splintery, from the mode of fracture; its most usual colours are reddish-white, milk-white, and very light grey, sometimes stained with dull yellow; and the splintery hornstone occasionally is marked with small irregular spots, supposed to be owing to the presence of chlorite.



Common Flint exhibits a vast variety of singular forms and appearances, most of which seem to be derived from organic bodies.

Calcedony occurs of different colours, as pale blue, grey, and sometimes, but more rarely, of a light green hue; it is crystallized in obtuse rhomboedrons; specimens of botryoidal calcedony are found in the Ferroe Islands; and nodules inclosing water (enhydrites) in volcanic rocks, at Monte Berico, near Vicenza, in Italy. Some specimens exhibit curious dendritic and other figures on the surface, of a red or black colour; they are called Mocha Stones, and are used for the covers of snuff-boxes, and for ornamental purposes. Carnelian is distinguished from calcedony merely by its colour, being red or yellow, and sometimes striped. Plasma is of a dullish green colour, often spotted with white. Heliotrope is a mixture of calcedony with green earth, occasionally containing particles of red Jasper interspersed, whence it is styled Bloodstone; some varieties are yellow spotted and semi-transparent. Chrysoprase is a beautiful variety of calcedony, which owes its applegreen colour to oxide of nickel. Pimelite is a similar green siliceous earthy mineral, which, according to Klaproth, contains a large proportion of water. Agates are siliceous compounds of an analogous nature, displaying variety of colour diversified by curved and angular lines, forming multitudes of singular and beautiful figures. Hence their several designations of striped, zoned, fortification, landscape, moss, spotted, and clouded agates.

The Jaspers form a multifarious division of siliceous minerals. The globular or Egyptian Jasper, of various shades of red, is found at Cairo, in masses supposed to be formed by infiltration; riband or striped jasper, generally of a brownish-red, with green bands, occurs in Siberia; agate jasper, found only in veins of agate, exhibits a diversity of colours, red, white, and yellow; porcelain jasper, which has a vitrified appearance, is produced by the operation of subterraneous heat on clay-slate.

Opal is inferior in beauty of appearance to few minerals, being distinguished by a peculiar chatoyant lustre or play of colours, arising from a multiplicity of minute and otherwise imperceptible fissures within its substance. These are the noble opals, the finest specimens of which are found in Hungary. The gyrasol, or fire-opal, from Mexico, displays usually reddish, yellowish, and greenish tints, with a flame-like iridescence, depending on interior fissures. The common opal and the semi-opal are destitute of the play of colours which characterizes the noble opal. Hydrophane, or Oculus Mundi, is white and opaque when viewed in the air, but is rendered transparent by immersion in water. Wood-opal is found of various colours, generally bright yellow, and its appearance betrays its nature, as opalized wood. Jaspopal exhibits red, brown, and yellow colours, and is sometimes spotted. Menilite, so called because it is found at Menil-Montant, near Paris, is nearly allied to common opal. All the opals are regarded as hydrates of silica.

a. Silicates with a Single Base.

Table-spar, or *Wollastonite*, found at Mount Vesuvius, Nagyag in Transylvania, and elsewhere, is a silicate of lime.

The *Silicates of Magnesia* are more numerous, including Steatite, which is white, or mottled like soap, and of various colours, the yellowish-green variety being among the most remarkable; Keffekil or Meerschaum, of which pipe-bowls are manufactured; Keffekillite, found in the Crimea; Lithomarge, sometimes of a reddish-yellow colour, and sometimes of a purple hue, but more frequently white.

Silicate of Zinc, called likewise electric or siliceous calamine, is obtained from Hungary and Siberia.

Silicate of Manganese occurs in varieties, which have been distinguished by different names, as allagite and rhodonite.

Silicate of Cerium, or *Cerite*, found at Bastnaes, in Sweden, contains yttria as well as oxide of cerium, and therefore belongs to the next division. (See p. 250.)

The *Silicates of Iron* include the Hisingerite, the Sideroschizolite, and the Chlorophæite.

The *Silicates of Copper* are Chrysocoll, Siliceous Malachite, or Mountain-green, which contains, according to Klaproth, Carbonic Acid, as well as Silica, and Water; and Dioptase, or Copper Emerald, a scarce mineral from Siberia.

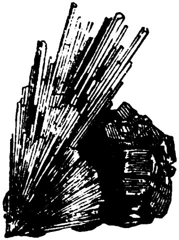
Silicate of Zirconia includes the common Zircon, and some hyacinths from Ceylon, and other countries; besides the variety called zirconite, and the blue zircon from Mount Vesuvius.

Among the *Silicates of Alumina* are the Kyanite or Disthene, and its varieties, the Bucholzite, and the Sillimanite. The hydrous silicates of alumina, or those containing water, exhibit considerable variety, including some kinds of lithomarge, fuller's earth, bole, cimolite, haloisite, &c.

Pinite occurs crystallized in equiangular, hexagonal prisms, of a blackish-green colour, imbedded in granite; and Gieseckite, found in Greenland, appears to be a variety of this mineral.

b. Silicates with Several Bases.

Apophyllite is a hydrated silicate of lime and potash; Mesotype, or Needle Zeolite, is a hydrated silicate of Alumina, Lime, and Soda, occurring in acicular tetraedral crystals, as in the following figure; Natrolite contains alumina and soda, but no lime; and Scolicite and Thomsonite are hydrated silicates of alumina and lime. Analcime is



a silicate of alumina and soda with a small quantity of lime. Stilbite is a hydrated silicate of alumina and lime, containing (according to Gehlen) a little soda. Laumontite, so called in honour of M. Gilles Laumont, who discovered it in the lead-mines of Bretagné, differs from the preceding in containing no soda, but some carbonic acid; it is subject to efflorescence when exposed to the air. Here may be mentioned Obsidian, of a black or smoke-grey hue, massive, with a conchoidal fracture; Pitchstone, green, reddish-brown, or nearly black, like pitch; and Pearlstone, of a dark bluish-grey colour, massive, but having a granular appearance, with a shining lustre.

Among the zeolitic substances may also be mentioned Prehnite, of which there are two principal varieties, the radiated or fibrous, which is of a green colour, and the foliated, in thin tabular crystals, of a greenish-white colour; both consisting principally of silica, alumina, lime, oxide of iron, and water, of which last body the foliated prehnite contains but a minute quantity; comptonite, a volcanic substance, found lining the cavities in lava; gmelinite, or hydrolite, and levine. In the same family is to be reckoned the harmotome, or cross stone, which has received the latter name from the peculiarity of its crystallization, and which consists of silica, alumina, barytes, and water; and the potash harmotome, which includes the Vesuvian minerals, styled zeagonite, gismondine, and abrazite.

To the Feldspar family belongs several important mineral bodies. Common feldspar is found exhibiting a diversity of colours, as white, grey, light red, green, and blue, crystallized in rhombic prisms, variously modified, imbedded in granite. Labrador feldspar is found massive and compact, displaying a beautiful variety of opalescent colours. Among the feldspathic minerals are Adularia, or Naker feldspar; Cleavelandite or Albite, containing soda; Leucite, or Amphigene; and Spodumene or Triphane, and Petalite, both aluminous silicates of the alkali called lithia. Nepheline, elæolite or fettstein, and wernerite, which includes the meionite of Vesuvius, scapolite, paranthine, and dipyre, are minerals more or less of an analogous nature.

The micaceous and talcose minerals form an interesting division of substances. Mica exhibits many varieties, which, with reference to their chemical characters, have been divided into potassa-mica, which is by much the most common; magnesia-mica, found at Mount Vesuvius, and at Munroe, in the state of New York, N. A.; and lithia-mica, or lepidolite, sometimes of a beautiful peach-red colour. Talc is found in considerable variety, as the Venetian talc, in foliated crystals of a greenish-white colour, a substance which forms the basis of rouge, used as a cosmetic; indurated talc; and agalmatolite (*talc graphique* of Hauy), a sectile mineral, which the Chinese form into cups, images, or other figures. Chlorite is a green mineral, crystallized in aggregated small modified rhombic prisms; and there are earthy and foliated varieties.

Among the amphibolic minerals, or those of the hornblende family, may be noticed the common, the basaltic, and the schistous hornblende; the actinolite, or strahlstein, divided into the glassy, the common, and the fibrous varieties; the tremolite, or grammatite, common and glassy; the arfvedsonite; and the anthophyllite, which contain silica, magnesia, and oxide of iron or lime; and most of them likewise contain alumina.

Serpentine, of which there are the noble and common varieties, exhibits various colours, green, brown, and red, often intermixed; and Serpentine-marble is ornamented with waving lines, as represented in the preceding figure. Chrysolite and Olivine, like serpentine, are coloured by oxide of iron.

The asbestine minerals in their chemical composition are related to the preceding. Among the most remarkable varieties may be mentioned, the flexible asbestus, or amianthus, used in making incombustible cloth; mountain wood, rock cork, and the blue and yellow asbestus, from South Africa, called krokydalite.

The pyroxenic minerals are numerous, including augite, found in small black crystals, imbedded in lava, the granular variety of which is called coccolite; diopside, including the mussite and the alalite, from Piedmont; the pyrgomme, or fassaite, which differs from augite in the form of its secondary crystals; and the achmite. To these may be added the Diallage, or schiller-spar, of a green, brown, or black colour, and having a metallic lustre; the bronzite, having much the colour and lustre of bronze; and the hypersthene, tinted with a mixture of brown, black, and copper colour, and exhibiting considerable metallic lustre.

The Epidote is a mineral of a green colour, massive or in large crystals, containing silica, alumina, lime, and oxide of iron; and some varieties also afford oxide of manganese. Zoisite resembles epidote in its chemical constitution, but it is generally of a bluish or yellowish-grey colour. Idocrase, or vesuvian, is of the colour of brown resin, and of a shining lustre, and is found in prismatic crystals, among substances ejected from volcanos; and of a similar composition is the hessonite, or cinnamon-stone; both these minerals containing silica, alumina, lime, and oxide of iron. Cyprine is a variety of the idocrase, tinted blue by the oxide of copper.

The Garnet family contains numerous and diversified varieties, which are silicates of alumina, tinged with oxide of iron or other metals. The pyrope, or chrome garnet, of a dark cherry-red colour, occurs in rounded and angular concretions, and likewise imbedded in serpentine and other rocks; the colophonite, so named from its resembling resin in colour and lustre, contains oxide of manganese, and a minute quantity of oxide of titanium; the melanite, or black garnet, according to Klaproth, is an aluminous silicate of lime and iron, with a trifling proportion of oxide of manganese; the grossular, or Wilui garnet, so called from the resemblance of its yellowish-green crystals to a gooseberry, is nearly of similar chemical composition; the allochroite, or splintery garnet, is not so hard as quartz, but strikes fire with steel, and melts before the blowpipe into a black enamel: it contains oxide of manganese, as well as oxide of iron, in considerable proportions; and analogous to these is the Romanzovite. The Gehlenite, so called from Professor Gehlen, an eminent mineralogist, is found in square prismatic crystals, of a light grey, olive-green, brown, or bluish-black colour. The Iolite, or dichroite, is so called from its different appearance when viewed in different positions, generally exhibiting a dull violet, or indigo colour; but if viewed by transmitted light, in the direction of the axis of the crystals, it appears of a pale yellowish-brown, or grey hue; and it occurs massive, or crystallized in hexaedral prisms: according to the analysis of Dr. Leopold Gmelin, it is an aluminous silicate of magnesia and oxide of iron, with small quantities of lime and oxide of manganese. Karpholite is a mineral of a deep straw colour, in radiated fibres or tufts; it has only been found at Schlackenwald, in Bohemia, and it appears to be a hydrated silicate of alumina, and the oxides of iron and manganese.

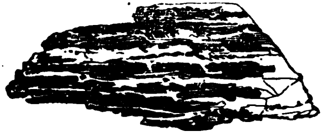
Staurolite, cross-stone, or granatite, is a bisilicate of alumine and oxide of iron.

Among the silicates containing yttria and protoxide of cerium are the Gadolinite, a very dark green mineral of a shining lustre, as hard as quartz, found at Ytterby, in Sweden; Allanite, a brownish, shining mineral, from Greenland; cerite, of a reddish-brown or crimson colour, found massive and disseminated; orthite, which resembles gadolinite, but occurs in thin veins in granite, and contains, besides yttria and oxide of cerium, oxide of manganese, alumina, lime, and water; and the variety called pyrorthite, which inflames before the blowpipe, containing one-fourth of carbon.

The silicates, containing oxide of glucinum (glucina), constitute a division of gems, including the emerald. The Emerald is found chiefly in Peru, crystallized in regular hexaedral prisms, of a fine green colour, which it derives from oxide of chrome. The beryl occurs in primitive rocks in various parts of the world, but especially in Siberia, resembling in the form of its crystals the emerald, but of a pale green or blue colour, containing oxide of iron, instead of oxide of chrome. Very large beryls have been found at Limoges, in France, and at Ackworth, in New Hampshire, N. A.; some crystals weighing more than fifty pounds. The euclase is a very scarce mineral, found in Peru and Brazil, of a pale or bluish-green colour, crystallized in rhombic prisms; and, according to Berzelius, consisting entirely of silica, alumina, and glucina. The chrysoberyl, or cymophane, occurs crystallized in tetraedral prisms, and variously modified, of a pale yellowish-green colour; and it is an aluminous silicate of lime, coloured by oxide of iron. Lazulite, or lapis lazuli, is the mineral which furnishes the pigment called ultramarine; according to an analysis of Klaproth, it contains silica, alumina, lime, sulphate of lime, and oxide of iron, to which last it was supposed to owe its azure colour; but it appears, from the more recent researches of Gmelin, that ultramarine is a double silicate of alumina and soda, coloured by combining with sulphuret of sodium, and it has accordingly been artificially manufactured in France, in large quantities. Lapis lazuli is found in rolled pieces, in various oriental countries. Haüyne, or latialite, is a mineral of somewhat analogous composition, containing, according to Vauquelin, silica, alumina, lime, and sulphate of potash, with a small quantity of oxide of iron, and a considerable proportion of some volatile matter. It exhibits various shades of blue, and is found imbedded in basaltic and feldspathic rocks, in granular concretions, and also crystallized in rhombic dodecaedrons.

Sodalite, so named from its containing a large proportion of soda, amounting to a fourth part of the mineral, is of a dark green colour, massive, or crystallized in rhomboidal dodecaedrons, imbedded in white feldspar. It has only been found in West Greenland, and since on Mount Vesuvius. Eudialyte is a silicate of soda, lime, and zirconia, with oxide of iron, oxide of manganese, muriatic acid, and water.

The Tourmalines and Schorls, with their varieties, might be placed with the Borates, as they contain boracic acid. The rubellite is a beautiful variety of the tourmaline, of a pale pink colour, sometimes imbedded in quartz. One of the finest specimens known of this mineral, in which the crystals are arranged in a radiated form, is preserved in the British Museum, having been originally presented to Colonel Symes by the King of Ava, and afterwards placed in Mr. Greville's collection. There are also red and blue varieties of the rubellite, chiefly from Massachusetts, N. A., and from Siberia; flesh-coloured tourmalines are found at Rozena, in Moravia; to which may be added the dark green variety, called the Brazilian emerald; and the asparagus green in Dolomite, from Campo Longo. Common schorl occurs in black acicular crystals, distinct and aggregated, imbedded in quartz or feldspar. Black schorl is, in various forms, found abundantly disseminated through the granites in general in the west of Cornwall, from Mousehole to the Land's End. A specimen of green tourmaline, analyzed by Gmelin, was found to contain, besides silica and alumina, oxides of iron and manganese, boracic acid and lithion; red tourmaline was found to be an aluminous silicate of potash, and oxide of manganese, with boracic acid and lithion; and black schorl contains silica, alumina, potash, soda, oxides of iron and manganese, and boracic acid and magnesia. Axinite is a mineral of somewhat analogous composition, containing silica, alumina, lime, and the oxides of iron and manganese. It occurs in thin, flat crystals, the primitive form of which appears to be a right prism with a rhombic basis, of a clove-brown colour, sometimes very pale, and sometimes approaching to grey. Beautiful large transparent crystals are found at Bourg l'Oisans, in Dauphiné, in France.



The Topaz family constitutes an abundant division of the minerals, containing silica and alumina; and from the large proportion of fluoric acid, which they also generally afford, they might perhaps, without impropriety, be reckoned among the fluorides. The characteristic colour of the topaz is yellow, but this gem is also found pink, blue, or colourless. It is found crystallized, in rhombic prisms, with pyramids, variously modified, and its cross fracture is always foliated. The topaz is said to be the most widely distributed among the precious stones, occurring not only in Brazil, but also in New South Wales, in Siberia and various other parts of Asia, in Saxony, in Scotland, and at St. Michael's Mount, in Cornwall. The pyrophysalite is found of a greenish-white colour, in irregular prisms, imbedded in quartz. The pycnite, formerly considered improperly as a variety of the beryl, occurs in thin, prismatic concretions, which are sometimes hexagonal, exhibiting either a pale lilac, a sulphur yellow, or a light straw colour. These two lastmentioned minerals, like the topaz, are compounds of alumina, silica, and fluoric acid.

Oxide of Titanium and Titanates.

Titanium is found in the state of oxide in various parts of the world, either in alluvial strata, or imbedded and crystallized. Rutile, or rutilite, also called titan schorl, is a brownish-red mineral, with a semi-metallic lustre, which occurs massive, and in rhombic tetraedral prisms; it is also found in capillary crystals, often curved, and crossing each other in all directions. Acicular and capillary crystals of rutile have been found inclosed in rock-crystal, in Brazil and elsewhere. This mineral appears to consist of peroxide of titanium. Anatase, or octaedrite, which is found in blue or party-coloured long octaedral crystals, at Bourg l'Oisans, generally associated with quartz and adularia, is a protoxide of titanium.

Sphene, or *Titanite*, is a combination of the oxide of titanium with silica and lime, which occurs imbedded in very oblique tetraedral prisms, with diedral terminations, wedge-shaped in each direction. Among the varieties of this mineral are those called brown and yellow menachan ore, in large crystals, found at Arendhal, in Norway; and pale green crystals, containing chlorite disseminated through them, from Mount St. Gothard. Pyrochlore, from Fredriksvarn, in Norway, is a compound of titanate of lime with titanate of uranium. Nigrine is of a velvet-black colour, and is found in rounded and angular grains, having a semi-metallic lustre. Iserine and menachanite have the appearance of black sand, slightly magnetic. These three lastmentioned minerals appear to consist chiefly of the oxides of titanium and iron; though, according to Dr. Thomson, iserine contains also a considerable proportion of silica, with some alumina and oxide of uranium. Crichtonite is a silicate of titanium, which is found in small, black, shining crystals with anatase.

Columbic Acid and Columbates.

Tantalite, or *Columbite*, is a mineral of a black colour, which crystallizes in oblique rhomboidal prisms, and which is very rare, having only been found in North America and in Bavaria. It appears to consist of the oxides of columbium, iron, and manganese. Yttrotantalite, found at Ytterby, in Sweden, is composed of oxide of columbium, yttria, and iron. Among the minerals which contain the oxide of columbium are also the Finbo and the Brodbo-Tantalites of Berzelius.

Antimonic Oxide or Acid, and Antimoniates.

Among the oxides of *Antimony* are Antimony Ochre, a straw-coloured mineral, often coating Grey Antimony, which evaporates before the blowpipe without melting; and White Antimony, which occurs in tetraedral flat crystals, or in tufts of delicate fibres, on quartz, galena, &c. Red Antimony, found in fine capillary crystals, stellated, of a red or tarnished purple colour, is a combination of the oxide of this metal with the sulphuret; and an argentiferous variety, of a fibrous texture, and reddish-brown colour, called Tinder Ore, is found in the Hartz mines, in Germany.

Tungstates.

Tungsten is found only in such a state of union with oxygen and other bodies, as to constitute mineral salts called Tungstates; the compound of this metal with oxygen, as it occurs naturally, having the properties of an acid, and, as such, entering into combination with the oxides of certain other metals.

The Tungstate of Lime (*Scheelin Calcaire* of Hauy), also named Scheelite or Tungsten, and from its great specific gravity, Heavystone, is a whitish or yellowish-brown mineral, which is found massive, or crystallized in octaedrons, coating other substances, in England, France, Saxony, Bohemia, and Sweden. At the British Museum is a specimen of the primitive (octaedral) crystal of this metallic salt, from Allemont, in Dauphiné. The Tungstate of Iron and Manganese, called Wolfram, occurs in the massive form, or crystallized in tetraedral tables, variously modified; hard and brittle, of a colour almost black, and a metallic lustre, but it soon tarnishes; it abounds in Cornwall, and is generally found in conjunction with the ores of tin, in primitive formations. The only other native Tungstate hitherto discovered, is that of Lead, occurring at Zinnwald, in Bohemia, and which was formerly mistaken for a molybdate of lead.

Molybdic Acid and Molybdates.

Molybdena, like Tungsten, forms an acid with oxygen, and mineralizes other metals.

Ochry Molybdena, which is found in Sweden and elsewhere, in the state of a yellow powder incrusting Feldspar, or the native Sulphuret of Molybdena, appears to consist of the acid of this metal. Molybdate of Lead occurs massive, disseminated, and foliated, or in lamellar hexaedral crystals, exhibiting various tints of yellow. It was first found in Carinthia, and has been since met with in Hungary, Austria, Saxony, Mexico, and Massachusetts, N. A., frequently imbedded in Quartz.

Chromic Acid and Chromates.

Chrome, or *Chromium*, is another acidifiable metal, though the Chromic Acid has not yet been found in a native state.

Protoxide of Chrome has been discovered in the department of the Rhone, in France, forming a green incrustation on other minerals, and it constitutes the colouring matter of the Emerald.*

Chromate of Lead, or Siberian Red Lead Ore, occurs in the gold-mines of Beresof, in a kind of micaceous rock, mingled with particles of quartz and brown ironstone, forming prismatic crystals of a deep orange colour, and sometimes accompanied by small green crystals, which are supposed to be Chromite of Lead, or a compound of the oxides of Chrome and Lead. Vauquelinite, a mineral accompanying the Red Lead Ore of Siberia, is a chromate of lead and copper. Chromate of Iron, containing also Alumina and Silica, has been found in France, in Maryland, N. A., and also in some places in Siberia, massive, or in octaedral crystals, of a black or bluish-black colour.

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* See p. 250.

Vanadic Acid and Vanadiates.

Vanadium being one of those metals that combine with oxygen in different proportions, forming acids as well as oxides, it enters into union with the oxides of other metals.

This metallic substance was first discovered in 1830, by Sefström, a Swedish chemist, in a kind of iron ore found at Taberg, in Smöland, but it has not been ascertained in what state the Vanadium exists in that ore. Shortly after the metal had been observed in Sweden, Mr. J. W. F. Johnston, of Edinburgh, found the Vanadiate of Lead in a mineral from the mines of Wanlock Head, in which the Vanadium constituted the principal electro-negative ingredient, though Chlorine, and the Arsenic and Phosphoric Acids were likewise present.* There are at least two varieties of the Wanlock-Head mineral: the first resembling arseniate of lead, occurring in mammillary tufts on the surface of calamine, and sometimes passing into the crystalline form; the other found amorphous, or in small round spots, of a black colour, like oxide of manganese, coating the calamine, or dispersed in cavities. Professor Del Rio has also found the Vanadic Acid combined with oxide of lead, in brown lead ore, from Zumpan, in Mexico.

Boracic Acid and Borates.

Boracic Acid is found existing in nature in the Lipari Islands, and likewise in the hot springs of Sasso, in Tuscany, whence the term Sassoline has been applied to it by some mineralogists. It occurs likewise in light crusts on substances in the neighbourhood of extinct volcanos.

Borax, called also Tincal, is a native Borate of Soda, found in Tibet, Persia, Tuscany, and it is said also in Peru and China. *Boracite*, or Borate of Magnesia, occurs crystallized in tubes, and variously modified, of a light grey colour, opaque or translucent, and the crystals are found imbedded in gypsum near Kiel in Holstein, and at Luneberg in Hanover. *Datolite*, a mineral of a pale greenish-white colour, massive or crystallized in cubes, sometimes modified, is found at Arendahl, in Norway; whence also is obtained a globular fibrous variety called Botryolite: both these minerals contain Boracic Acid combined with silica and lime.

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* Report of the British Association for 1832, p. 470.

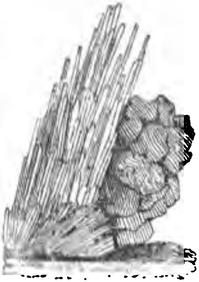
Carbonates.

Carbonate of Soda is found in some mineral waters, and most abundantly in the lake called Lagunilla, in Venezuela, S. A., from which the salt is procured as an article of commerce. A combination of the Carbonate and Bicarbonate of Soda is obtained in large quantities in the saline state, from the oasis of Gadamis, west of Fezzan, in Africa, where it is called Trona. According to an analysis made by Mr. Richard Phillips, it consists of three parts of acid and two of soda, and hence he terms it a Sesqui-carbonate of Soda.

Strontianite is a rare mineral, of a greenish colour, found in radiated masses, and sometimes in acicular hexaedral crystals, generally imbedded in earthy barytes, and associated with galena; it was first obtained from Strontian, N. B., and has since been discovered in Saxony and in Peru. Witherite, or carbonate of barytes, occurs in large masses in diverging fibres, or crystallized in hexaedral prisms and pyramids; forming sometimes beautiful groups of double pyramidal crystals, the primitive form of which is an obtuse rhomboid. It has been found in Lancashire, and other northern counties of England, and also in Shropshire and in Wales. Baryto-calcite, is a compound of the carbonates of barytes and lime, which occurs in Cumberland, and was at first supposed to be a variety of carbonate of barytes, but it differs in crystallization, its primitive form being an oblique rhombic prism.

Carbonate of Lime.—This division of the carbonates comprehends the multifarious varieties of calcareous spar, marble, chalk, and limestone, many of which are much more interesting in a geological than in a mineralogical point of view, and therefore will here require but a brief notice.

Arragonite is a mineral of a white colour with a pearly lustre, and sometimes with a reddish hue, which occurs in hexaedral crystals, aggregated, grouped, or imbedded in gypsum, also arborescent, dendritic, or stalactitic, and likewise in acicular fibres, one variety of which has been called Flos Ferri, from its resemblance to a delicate white flower. It has been found in Arragon, Bohemia, Styria, and France. Some specimens are found to contain three or four per cent. of Carbonate of Strontian. Calcareous Spar is a carbonate of lime in transparent crystals, the primitive form of which is a rhomb, passing into almost innumerable varieties; its colour is various, but it generally exhibits light tints. Among the sub-varieties may be mentioned the dogtooth spar, with double hexaedral pyramids, joined at their base, and the short hexaedral prismatic crystals turned so that the lines of the pyramids correspond. This mineral, frequently called the Iceland Spar, is peculiarly interesting, as having furnished the means for the discovery of the double refraction of light. It is found in Iceland, in the Hartz Mountains of Germany, and in Derbyshire, where it occurs in large crystals, of a topaz-yellow colour, and that kind called Fontainebleau Sandstone, contains a considerable admixture of quartz. Stalactitic Limestone formed by deposition from the water of springs holding carbonate of lime in solution, is of various colours, as white, green and brown, sometimes in the form of long tubes, in that of icicles, botryoidal masses, and a variety of other figures, one of which is represented in the margin. It is frequent found pendant from the roofs, or incrusting the walls of caverns, as in Derbyshire, the Island Sky, St. Michael's Cave, Gibraltar, and in the famous Grotto of Antiparos, in the Archipelago. Satin Spar is a fibrous variety of carbonate lime, of a snow-white, bluish, or green colour which has derived its name from its peculiar pearly lustre, and which is found in Cumberland and in Sweden.



Those limestones which admit of beafinely polished, are generally termed marbles, of which there are a great many varieties. The white granular limestone, or marble of the primitive rocks, which is the most highly esteemed, is to be distinguished from the secondary limestone by the entire absence of organic remains, by its granularly foliated structure, and by its association with other primitive substances. The most valuable kind of statuary marble is the Parian, and that of Mount Pentelicus, near Athens, of which are formed some of the finest existing sculptures of antiquity. The marble of Carrara, in Italy, is also celebrated for its beauty, and having been much employed by sculptors; it is of a milk-white hue, and less crystalline than the marble of Paros. Many of the varieties of figured and coloured marbles are extremely beautiful, deriving their characteristic peculiarities from the admixture of various foreign bodies. There is a kind of marble found in Tirey, one of the Western Islands of Scotland, of a reddish colour, which contains sahlite, and probably titanium imbedded. Cipolin is a sort of statuary marble, with veins of *Mica*. Brocatella is a breccia limestone, composed of fragments of a yellowish-red and purple colour, cemented by similar transparent calcareous spar. Verde Anticho and Verde di Corsica, are composed of compact limestone and calcareous spar, with serpentine and asbestus; and of a similar nature is the variety called Mona marble. Florentine marble is a greyish compact marble, with argillaceous earth, exhibiting designs of landscapes or ruins, in yellowish-brown tints. Lumachella marble is a compact limestone, of a brownish-grey colour, in which are imbedded shells. Lucullite, or black marble, containing carbonaceous matter, is found in Derbyshire, and used for ornamental architecture and other purposes. Madreporite, or prismatic Lucullite is so called from its resemblance in structure to Madrepores. Swinestone, or stinkstone, is a variety of limestone, containing bitumen in various proportions, whence it derives a fetid odour. Much of it is found on the banks of the river Avon, near Bristol; and there is a sectile variety met with in Dalmatia, said to be about the consistence of soap.

Oolite, or Roestone, is a variety of carbonate of lime, which derives its appellation from its structure and appearance, being composed of minute globular concretions, of a yellowish-brown or straw colour, much used in building, under the names of Portland Stone and Bath

Stone. Pisolite, or peastone, somewhat resembles the preceding, but consists of larger concretions, composed of concentric layers surrounding grains of sand, formed by deposition from hot springs, as at Carlsbad, in Bohemia, and at Tivoli, in Italy. Calcareous Tufa is an earthy carbonate of lime, of a porous spongy structure, forming casts or incrustations by deposition from water. Casts of medals have thus been obtained, by placing them in moulds to receive the spray impregnated with calcareous particles, and incrustations of a similar nature are obtained from springs at Matlock and at Knaresborough, where they are sold as petrifactions.

Chalk and its varieties, Rock milk and Agaric mineral, are carbonates of lime; and Marl is chiefly composed of the same substance mixed with argillaceous earth.

Carbonate of Magnesia.—Magnesite, which is a carbonate of magnesia, generally white and friable, or in fine acicular crystals, has thus been found in Piedmont, and in Moravia; likewise at Hoboken, in New Jersey, N. A., in veins in a serpentine rock, accompanying the native hydrate of this earth; and a variety has been obtained from the East Indies, which is white, massive, hard, of a conchoidal fracture, and translucent at the edges. The carbonate of magnesia more frequently occurs combined with that of lime, as in the Dolomite, which is of a snow-white colour, and granular texture, often containing realgar and pyrites. A variety of dolomite, found in Massachusetts, N. A., and elsewhere, exhibits a considerable degree of flexibility. Rhomb Spar, or bitter spar, is a mineral of a yellowish or brown colour, which occurs, imbedded in chlorite schist, in the Tyrol, at Saltzburg, and in Sweden. Miemite, Tharandite, and Pearl Spar, are varieties of magnesian limestone.

Among the Carbonates of Iron are Sparry Iron ore, of a greyish or yellowish-white colour, crystallized, fibrous, massive, and botryoidal; which last variety has been termed Sphærosiderite. This carbonate has been found in Cornwall, crystallized in hexagonal prisms, but its more usual form is the equiaxial rhomb.

Carbonate of Manganese, is found in globular or botryoidal forms of various shades of rose colour, with sulphuret of manganese and oxide of iron.

Calamine, or carbonate of zinc, is found in tabulated crystals, generally tetraedral, and in acute rhombs, also compact, botryoidal, and in other forms, of various shades of colour, generally either green or brown.

Carbonate of Lead, or sparry lead ore, exhibits considerable variety of form. The compact carbonate, of a snow-white or cream colour and shining, is commonly associated with galena. It is also found semitranslucent, crystallized in double hexagonal pyramids on galena; and it occurs in fibrous or caniculated crystals, sometimes coloured by green carbonate of copper. The earthy or pulverulent varieties are of a brown or cream colour.

Carbonate of Copper exhibits some remarkable varieties, some of which have been used as pigments under the name of mountain blue. Among these carbonates are the velvet copper ore, of a brilliant light blue colour, found only at Oravitza, in the Bannat, forming a velvet incrustation on malachite and brown ironstone. The green carbonates include fibrous malachite, occurring in acicular or fascicular and stellated crystals, and also foliated; compact malachite is found massive, mammilated, with a zoned fracture, or crystallized in octaedrons or dodecaedrons, detached or imbedded in red copper ore.

Arsenious Acid and Arseniates.

Arsenious Acid.—This acid, in the native state called also arsenic bloom or octaedral oxide of arsenic, has been often confounded with arseniate of lime: it occurs stalactitic, in delicate flat crystals or in silky filaments, of a white colour, incrusting other minerals.

Pharmacolite is a combination of arsenious acid and lime, found in capillary crystals, which look like little tufts of cotton. Arseniate of Iron, or pharmacosiderite, is found chiefly in small cubic crystals in the tin-mines of Cornwall, and in other parts of the world. Skorodite, which appears to be a cupreous arseniate of iron, is found in minute blue or greenish rhombic crystals, generally accompanying the preceding mineral. There are several varieties of Arseniate of Copper, as the octaedral arseniate of a sky-blue or emerald-green colour, in flat crystals; the tabulated arseniate, in flat hexaedral crystals, of an emerald colour; the triedral arseniate, of a blackish or shining blue colour, crystallized in rhombic prisms, sometimes with diedral summits, and also flat, curved, aggregated, and variously modified; and the fibrous arseniate.

The Arseniates of Cobalt, or red cobalt ores, comprise the earthy and the radiated varieties, the former of which is a soft, friable mineral, of a rose colour, sometimes forming very small botryoidal concretions in the cavities of grey cobalt; and the radiated variety consists of delicate acicular crystals, sometimes of a stellular figure, found upon other minerals in Cornwall, Scotland, Saxony, Hungary, and Norway.

Arseniate of Lead occurs, in slender, hexagonal crystals, upon quartz and steatite, in Saxony, Siberia, and especially in Cornwall. There is a reniform arseniate of lead in lamellar concretions, of a yellowish colour, found in Siberia.

Phosphates.

The Phosphates of Lime include some varieties. Apatite is a mineral of a greyish or green colour, crystallized in hexaedral prisms or tables, and variously modified. Some specimens are found of a violet colour; the green and blue varieties are called Moroxite, and the pale yellow-green asparagus-stone and this phosphate is sometimes found of a snow-white colour. Phosphorite, formerly supposed to be of the same composition with fluor spar, is a phosphate of lime, generally of a light reddish-brown or whitish and yellowish colour, in distinct concretions, earthy or massive, found in Hungary and elsewhere.

Phosphate of Lead, or pyromorphite, is found massive, crystallized in hexaedral prisms, dendritic, or earthy and friable, of a green and yellow colour; and also in hexagonal prisms and acicular crystals, of a deep orange or brown colour.

Phosphate of Yttria, or phosphyttrite, is a very scarce mineral, first found in granite, at Lindenas, in Norway; and afterwards, in similar small quantities, at Ytterby, in Sweden.

Phosphate of Iron occurs in rhombic prisms, striated, acuminated, and variously modified, of a green colour; it is also sometimes found of a blue colour, and likewise black. These varieties, except the last, have been found in Cornwall; the earthy, blue iron ore, and wood, peat, and clay, impregnated with this mineral, have been met with in New Jersey, N. A.

Phosphate of Manganese, or triplite, is a mineral of a shining black or brownish-black colour, which melts before the blowpipe into a black enamel.

Phosphate of Copper has been found near Cologne, in Germany, of a green colour, in small rhomboidal crystals. Among the varieties of this phosphate may be specified the olive malachite, or octaedral phosphate, found at Lebethen, in Hungary; and the prismatic variety, called pseudo malachite, from Rheinbreitenbach, where it is found with quartz, sometimes passing into Calcedony.

Phosphate of alumina appears to form the basis of several minerals, the composition of which, however, has not been perfectly ascertained. Among these are the Wavellite, formerly called hydrargillite, found in Devonshire, Ireland, Bavaria, Bohemia, Greenland, and Brazil, forming globular concretions, or fibrous and radiated groups; the Klaprothite, called also blue spar or azurite; the Calaite, or real turquois, an opaque gem found principally in the province of Khorasan, in Persia, imbedded in a ferrugino-argillaceous rock; the Kakoxene, a rare substance found in Bohemia, in the fissures of argillaceous ironstone, and exhibiting a crystalline fibrous structure, and a yellow colour; and the Childrenite, found at Tavistock, in Devonshire.

The Phosphate of Uranium includes the yellow uranite, or uran mica, found in France, in thin, quadrangular crystals; and the green uranite, or chalcolite, in tetraedral tables, aggregated and detached, or elegantly grouped, which has been obtained chiefly from Cornwall, and from Saxony.

Nitrates.

Nitrate of potash, or native saltpetre, is found as an efflorescence, consisting of capillary crystals, incrusting chalk and limestone rocks, at Pulo di Molfetta, in Apulia in Italy, near Burgos in Spain, and elsewhere. In the vicinity of Evreux, in France, nitre is collected from the surface of the calcareous soil several times in the year; and it is obtained largely in the same manner, for the purposes of commerce, in the East Indies, and other parts of the world.

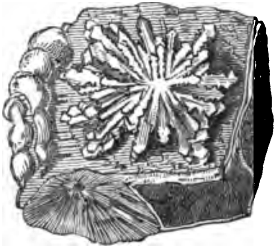
Nitrate of lime is often found combined with that of potash, and may sometimes be observed forming silky efflorescences on old walls; it likewise occurs in some mineral waters.

Sulphates.

The sulphates are a numerous class of minerals, including many of the soluble salts. Sulphate of soda, or glauber salt, is frequently found as an efflorescence, and sometimes in acicular crystals, near mineral springs and salt lakes. Thenardite is a hydrous sulphate of soda, found in crystalline crusts at the bottom of the briny waters at the Salines d'Espartines, in the neighbourhood of Madrid. Glauberite is a mineral composed of the anhydrous sulphates of soda and lime, found imbedded in salt and clay in the salt-mines of Villarubia and Aranjuez, in Spain. Reussite is a sulphate of soda, combined with sulphate of magnesia.

Celestine, or sulphate of strontian, a mineral of which there are several varieties, is found near Bristol, in France, the Tyrol, Spain, Sicily, and Pennsylvania, N. A. It occurs of a sky-blue or grey colour, and sometimes of a white, yellowish-white, or brown; massive and foliated, in tabulated crystals, in radiated fibres, or compact in hollow balls, with internal crystallizations.

Sulphate of Barytes, or heavy spar, exhibits a considerable variety of crystallization, the primitive form being a right prism with rhombic bases. It forms large wax-like, yellow crystals, and is found in Cumberland, at Schemnitz in Hungary, Clausthal in the Hartz, Traversella in Piedmont, and elsewhere. The radiated or stellated variety of this sulphate includes the Bologna stone of Monte Paterno, used in the preparation of the Bononian phosphorus. (See marginal figure.) To these may be added the beautiful variety called chain spar, from the Hartz; the fibrous and the granular varieties; the prismatic barytes, generally of a brown-yellow colour; the compact, called barytic or ponderous marble; and the fetid or hepatic barytes, of a smoke colour, which occurs massive and nodular.



Sulphate of Lime is found in abundance in France, Spain, and other parts of the south of Europe, exhibiting some varieties, among which may be specified selenite, or sparry gypsum, in hexagonal prisms, or variously modified, sometimes stained of a yellow colour by oxide of iron; fibrous gypsum, opaque or translucent, of a snow-white hue, with a silky lustre; granular gypsum, or alabaster; compact gypsum, white or variegated, and with red and white veins, which variety includes the stalagmitic gypsum of Guadaloupe. Anhydrous sulphate of lime, (likewise styled anhydrite, cube-spar, and muriacite), is composed, as its name implies, of sulphuric acid and lime, *without water*; and it is found crystalline, fibrous, granular, and compact, chiefly of a milk-white or bluish colour. Anhydrous sulphate of lime, containing silica, has been found in Italy, where it is called Marmo Bardiglio di Bergamo, and by Count Bournon, Bardiglione; and a variety occurs in the salt-mines of Wieliczka, in Poland, which, from the peculiarity of its structure is termed tripestone.

Sulphate of Magnesia, which is of common occurrence in mineral waters, as those of Epsom and Cheltenham, is found in capillary or fibrous crystals at Calatayud in Arragon, and in the mines of Idria; and what is called stalactitic cobalt vitriol, from Herrengrund, in Hungary, is merely sulphate of magnesia, tinted red by oxide of cobalt.

Polyhalite, formerly supposed to be anhydrous sulphate of lime, appears from the analysis of Stromeyer to consist of the sulphates of lime, magnesia, and potash, muriate of soda, and oxide of iron, in a state of chemical combination, though the muriate and oxide occur in very small proportions.

Sulphate of Zinc is a semi-transparent saline mineral, of a greyish or reddish-white colour, which seems to be produced from the decomposition of blende, the sulphuret of this metal.

Sulphate of Iron, copperas, is another product of spontaneous decomposition, being derived from martial pyrites, and appearing in the massive form, or in stalactitic fibres, yellow scales, or red concretions.

Sulphate of Cobalt is a soluble saline body, of a pale rose or flesh colour, and of an earthy texture, usually in the stalactitic form, found in the Hartz mines and elsewhere.

Sulphate of Copper is found in crystals of a fine blue or purple colour, but rarely of any considerable size or perfect form.

Sulphate of Lead occurs crystallized in cuneiform octaedrons, variously modified or aggregated, imbedded in cellular quartz, tinged by oxide of iron. Translucent crystals, of a yellowish-grey colour, have been obtained from Parys Mountain, in the Isle of Anglesea.

Sulphate of Alumina displays some variety of form and composition. Native alum is found crystallized, fibrous, and in other states, in various places; aluminite, or websterite, is a hydrated subsulphate of alumine, mixed with sulphate of lime, resembling pure porcelain earth, found on the coast of Sussex, near Newhaven, and at Halle, in the territory of Magdebourg. Alumstone, likewise called aluminite, or alunite, occurring in large quantities in a hill at Tolfa, in the Pope's dominions, contains potash as well as sulphuric acid and alumina; and from this mineral is prepared Roman alum.

FLUORIDES.

The fluor minerals, formerly regarded as fluates or combinations of an acid with oxidated bases, have been ascertained to consist of the electro-negative body fluorine, united with different metals.

Fluor spar, erroneously named fluate of lime, is a fluoride of calcium, found in several parts of the world, and exhibiting various forms and colours. It occurs compact, foliated, crystallized, granular, and earthy: from Chamouny are obtained rose-coloured crystals; from Siberia, a variety called Chlorophane, which emits a brilliant green light when heated; and there is a figured variety called Fortification Fluor. (See marginal figure.)

Yttrocerite, a violet-coloured mineral, found imbedded in quartz, at Ytterby, in Sweden, is a combination of the fluorides of calcium, yttrium, and cerium.

Fluate.

Cryolite, is a mineral found in West Greenland, which derives its name from its extreme fusibility, melting like ice: it appears from the analyses of Vauquelin and Berzelius, to be a compound of fluoric acid, alumina, and soda. It is of a colour approaching to white, translucent, amorphous, having a foliated fracture, and softer than fluor spar.

CHLORIDES.

The chlorides are an important class of minerals, the nature of which, like that of the fluorides, was formerly greatly misapprehended.

Chloride of Sodium, long known to chemists by the appellation of muriate of soda, is not only found most abundantly in solution in sea-water, brine springs, &c., but also occurs in vast masses in the state of rock-salt, at Cordova in Spain, Wieliczka in Poland, in Hungary, Siberia, Africa, and the Andes of South America. It crystallizes in cubes; and among its varieties are the fibrous, red, blue, and violet, and the stalactitical rock-salt.

Chloride of Ammonium, or rather muriate of ammonia, native sal ammoniac is found chiefly in the vicinity of volcanos.

Among the Chlorides of Lead are the Cotunnite, from Mount Vesuvius; the basic muriate of lead, found in the mines of Mendip; and the murio-carbonate of lead, a rare mineral, found in Derbyshire, crystallized in square prisms terminated by pyramids, of a yellow colour, of which there are fine specimens at the British Museum.

Chloride of Copper, or atacamite, is a mineral which forms beautiful groups of green crystals, found in Chili and Peru.

Chloride of Silver, called corneous silver or horn silver, from its appearance, is found massive and crystallized; in colour and form resembling gum arabic; or of a pale yellowish-green or brown, botryoidal, lamellated, earthy, or crystallized in minute cubes and octaedrons.

Chloride of Mercury, which has the same horny appearance, crystallizes in small square prisms, terminated by flat pyramids, and otherwise modified. It is so soft as to be sectile; and it becomes volatilized before the blowpipe.

ORGANO-CHEMICAL SUBSTANCES.

Salts.

Mellate of Alumina, called Mellite or honeystone, from its appearance, is found in small amber-coloured crystals, in beds of brown coal, in Thuringia.

Oxalate of Iron, also called Humboldtite, was formerly considered as resinous iron ore.

Resins.

Amber exhibits numerous varieties, arising from various causes; and some specimens are extremely curious, from the bodies imbedded in them. It occurs in rounded pieces, rough on the outside, and within of a yellowish, white, or reddish colour; and is found on the coast of Norfolk, Prussia, Mozambique in Africa, and other parts of the world.

Fossil copal, or Highgate resin, a substance somewhat resembling amber, found in making excavations for the road at Highgate.

Retinite, or retinasphalt, a mineral from Bovey, in Devonshire, of a yellow and reddish-brown colour, which burns with a fragrant odour.

Bitumens.

Varieties—Naphtha, petroleum, elaterite or elastic bitumen, and indurated petoleum.

Coal.

This substance presents some varieties, more interesting to the geologist than to the mineralogist; and of these some notices may be found in another part of this volume.*

CRYSTALLOGRAPHY.

Solid bodies appear under a vast variety of forms, some depending on organization, and others on molecular attraction; the latter of which only require to be considered at present. These forms or modes of aggregation are either regular or irregular; consisting in the one case of geometrical solids, variously modified; and in the other, of amorphous solids, or those which display no symmetrical proportions,

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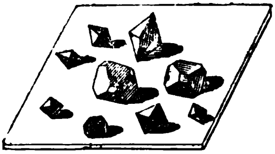
* See Oryctology.

Certain figures, arising from molecular attraction, are termed crystals, constituting polyedral solids, terminated by surfaces, regular, connected, and often shining with a lustre equal to that of a polished gem. Few objects of this kind are more beautiful than frozen water, as it occurs in the state of large snow-flakes, when examined by a microscope; or as it may be observed in the hoar-frost, incrusting with most delicate network our trees and hedges, or formed by the congelation of moisture on the panes of windows in a cold winter's morning.*

Those bodies which are capable of crystallization have been observed to affect peculiar forms: thus rock-crystal frequently occurs beautifully transparent in hexaedral prisms, terminated by six-sided pyramids; the Derbyshire fluor spar crystallizes in cubes, as likewise does common salt; alum, or sulphate of alumine, forms octaedral crystals; and sulphate of magnesia tetraedral prisms. These forms, however, are liable to modification and diversity from different causes, as will be subsequently explained. Fluor spar and galena sometimes exhibit octaedral and sometimes cubic crystals; and carbonate of lime appears in such a variety of forms that it is difficult to decide which is of the most frequent occurrence. "Comte de Bournon, in his elaborate treatise on this mineral, has enumerated fifty-six modifications; which, differently combined, furnished him with above six hundred varieties of form."†

The figures of crystals may be conveniently observed by making solutions of several salts in water, suffering small portions to crystallize, by evaporation, and then examining them through a microscope. Take a dram of alum, and similar quantities of common or table salt, Epsom salt, glauber salt, nitre, or any other soluble saline substances; and place them, separately, in clean wine-glasses or gallipots, then pour on each parcel rather more than enough water to cover it; and stirring the liquors frequently, after they have stood half an hour, let a drop of each fall on a strip of clean

Alum.



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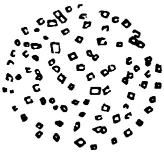
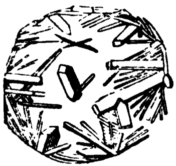
* See Treatise on Meteorology.

† Mrs. Lowry's Conversations on Mineralogy, 2d edit., vol. ii. p. 26.

Common Salt.



Epsom Salt.



Glauber Salt.

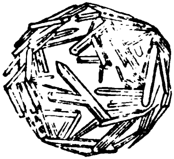


plate-glass, and place it in the sun or on the chimney-piece, protected from the dust, so that the water may be driven off; and more or less regular crystals will be formed, having a pleasing appearance when viewed through a microscope. The marginal figures will afford some idea of the manner in which the crystals of the different salts above mentioned are grouped and constituted.

The modifications of form which are observed in crystallized bodies are sometimes owing to the sudden and consequently irregular aggregation of the crystalline particles; and sometimes the presence of foreign bodies may accelerate, interrupt, or very materially interfere with the process of crystallization. Hence the angles or edges of crystals may be truncated or rounded, and cylinders, spherical, lenticular, or agglomerated masses may be produced, bearing but a faint resemblance to the proper form of the salt. In order to obtain regular, large, and well-shaped crystals of any salt, a saturated solution should be made in distilled water, and set by in a moderately warm situation, where it may remain undisturbed, so that the fluid may evaporate slowly; and a gradual deposition of the saline particles will then take place, yielding symmetrical crystals of a larger size than can be produced by any other management.

The interesting appearance of certain crystals, and their relative permanence of form, amidst a seeming variety, drew forth some striking observations from Dr. Freind, in his lectures on chemistry at Oxford, in the early part of the last century. "The beauty and variety of the figures of crystals is so admirable, that there is scarcely any thing in nature which can entertain the eye more agreeably. These figures are sometimes seen by the naked eye, but by the help of microscopes are discerned much better. In Common Salt we plainly discover quadrilateral pyramids, with square bases; in sugar, the same pyramids, *Nitre.*

with oblong and rectangular bases; in alum, they rise with six sides, supported by an hexagonal base. The crystals of vitriols very much resemble icicles, united one to another with great variety; among which lie some polygons, as may be discovered by the naked eye. Sal ammoniac very elegantly imitates the branches of a tree; and salt of hartshorn (carbonate of ammonia) looks like a quiver of arrows. Glauber's Sal Mirabilis, which is made of common salt and vitriol (sulphate of soda), exhibits the figure of both salts. Nitre appears in certain prismatical columns, not much unlike bundles of sticks; among which there are interspersed some rhomboids[*] and some pentagons, which seem to come very near those of common salt. Hence Lemery has justly remarked, that Nitre could not be purified by any art or contrivance whatever; but something of a Sal Gem, or fossil salt, would stick to it. But salt of tin outdoes all for beauty, in which are lines like little needles, which spread themselves every where from a point, as from a centre, so as to represent a star, much like what we see in the regulus of Mars (metallic iron)."[†]

Dr. Freind proceeds to remark, that it is a circumstance "very peculiar in these salts, that let them be never so divided, and reduced into minute particles, yet when they are formed into crystals, they each of them reassume their proper shape: so that one might as easily divest and deprive them of their saltness as of their figure." The intimate relation between crystalline form and chemical composition, which attracted the attention of this ingenious writer, has been extensively investigated by more recent inquirers. Among the facts which have been disclosed in consequence of their researches, one of the most singular and important is that bodies, both simple and compound, which are capable of crystallization, appear to form groups characterized by similarity of structure; so that one group may include several substances, all crystallizing in similar square prisms, another group consists of bodies forming similar octaedral crystals, and various others, the members of which respectively are distinguished by peculiar figures. As an example of such a group of minerals may be mentioned calc spar (Iceland crystal), bitter spar, carbonate of magnesia and iron, carbonate of iron, manganese spar, zinc spar, and magnesia spar, all crystallizing in rhomboedrons. The discovery of this disposition among mineral bodies differently constituted to assume a common form, led to the assumption of the doctrine of Isomorphism, already alluded to in the Treatise on Chemistry.* The law of isomorphism, as announced by Mitscherlich, in its utmost generality, is as follows: "The same number of atoms combined in the same way produces the same crystalline form; and the same crystalline form is independent of the chemical nature of the atoms, and is determined only by their number and relative position."†

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[*] Nitre sometimes consists partly of nitrate of soda, which forms rhomboidal crystals; but nitrate of potash, when quite pure, crystallizes in hexaedral prisms, generally with diedral summits.

[†] Chymical Lectures, by John Freind, M.D., 1712, pp. 144—146.

The discussion of the subject of isomorphism to any considerable extent would be impracticable here, even if it could be rendered as generally intelligible and interesting as it is important. Those readers, therefore, who may be inclined to pursue the progress of research relative to this topic, must be referred to the details contained in a paper on the Progress of Chemical Science, by Mr. Johnston, published in the Report of the British Association for 1832; and to a list of Isomorphic Bodies, by Professor Miller, in the same volume. A few observations, however, may be added to explain in some degree the general principle on which depends the association of isomorphic substances. An examination of the group of rhomboedral minerals mentioned above, will demonstrate amidst diversity of composition a similarity of atomic constitution. All those bodies of which crystallised carbonate of lime, or calc spar, may be regarded as the isomorphic type, appear to correspond in the number of their atoms with that body: thus,

Calc Spar consists of 1 Carb. Acid + 1 Lime.
Bitter Spar . . . 1 Carb. Acid + 1 Lime + 1 Carb. Acid + 1 Magnesia.

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* See p. 120.

† Report of British Association for 1832 p. 422.

Carbonate of Magnesia and Iron consists of 1 Carb. Acid + 1 Magnesia + 1 Oxide of Iron.
Carbonate of Iron . . . . . 1 Carb. Acid + 1 Oxide of Iron.
Manganese Spar . . . . . . 1 Carb. Acid + 1 Oxide of Manganese.
Zinc Spar . . . . 1 Carb. Acid + 1 Oxide of Zinc.
Magnesia Spar . . . . . . 1 Carb. Acid + 1 Magnesia.

In all the simple carbonates of the preceding group, one atom of carbonic acid is combined with one atom of a metallic protoxide; and in the compound carbonates the atomic quantities are doubled. The same correspondence of atomic constitution seems to prevail in groups of more complicated chemical combinations: thus tremolite and anthophyllite are double silicates, the composition of which is as follows:

Tremolite consists of 1 Lime + 1 Silica + 3 Magnesia + 2 Silica.
Anthophyllite . . 1 Oxide of Iron + 1 Silica + 3 Magnesia + 2 Silica.

Hence it appears that the only difference between these bodies consists in the former containing one atom of lime (protoxide of calcium), and the latter one atom of protoxide of iron; and they both crystallize in oblique prisms. In numerous other cases it has been found, that one oxide or acid having the same atomic constitution with another oxide or acid, may replace it, or be substituted for it in the composition of minerals, giving rise to similar crystalline forms; and thus groups are produced, each composed of two or more bodies corresponding in the numbers of their atoms, and in crystalline form.

There is an inferior degree of analogy of form observable among minerals, which probably arises, as in the cases already noticed, from the atomic constitution of bodies. Certain crystalline compounds are found to differ among themselves merely in the angular measurements of their crystals. Thus sulphate of barytes, sulphate of lead, carbonate of lead, and some others, form right rhombic prisms; but the obtuse angles of the rhombic prism of sulphate of barytes measure

101° 42′; those of sulphate of lead 103° 42′; and those of carbonate of lead 117° 18′.[*] Hence groups of bodies thus related are said to be *plesiomorphous*;[†] and the term *homoiomorphous*[‡] has been adopted to distinguish groups of crystalline substances differing more widely in their angles. It has also been remarked, that while differently constituted compounds may agree in crystalline form, there are bodies, both simple and compound, which are capable of existing under two forms, which are incompatible or not derivable from one common form. Sulphur is found crystallized in octaedrons with rhombic bases, and also in rhombic prisms. Pure carbon occurs in nature in two states, constituting the diamond and graphite; the former exhibiting regular octaedral crystals, and the latter crystallizing in hexaedral plates, striated parallel to some of their sides. Sulphur and carbon thus display a duplicity of form, a property in these and other bodies denoted by the term *dimorphism*.[§]

The phenomena of plesiomorphism, homoiomorphism, and dimorphism, which have all an obvious relation to isomorphism, indicate the necessity of further researches to elucidate the nature and causes of these appearances, which may probably lead to very curious and interesting discoveries.

The modifications and seeming anomalies of form which often occur in crystallized bodies take place under certain laws; the deviation from the usual figure of the crystal depending on addition or subtraction of parts necessary to make up the regular solid, or primary form of a mineral, in any given case. That the varieties of form in crystals of the same mineral may be referred to truncations of an invariable primary nucleus, was an opinion that appears to have been started by the French mineralogist, Romé de Lisle; the idea also occurred to Gahn, professor of mineralogy at Upsal, who having broken a piece of the dogtooth calcareous spar, observed that it was throughout composed of rhomboidal crystals: and hence Professor Bergmann was led to conjecture that in all crystallized bodies there must exist a primary nucleus. The inquiry was then taken up by the Abbé Haüy, who is said to have had his attention drawn to it by an accident in itself somewhat awkward and perplexing. A person of fortune who had collected a cabinet of minerals as expensive curiosities, was showing them to M. Haüy; and, handing to him one very beautiful crystalline specimen that he might inspect it more readily, the stone slipped from the hand of the visiter, and falling on a marble pavement, was split in several pieces, which the owner regarded as worthless, while courteously accepting the apologies of the chagrined philosopher, ordered a servant to take up and throw away. M. Haüy struck with the brilliance of the smooth surfaces of the fractured parts, begged to be allowed to inspect them, and took them home to examine the structure of the mineral more at leisure. He found that it was susceptible of cleavage only in particular directions, and to a certain extent; and having made corresponding observations on other crystallized substances, he was at length enabled to reduce to a regular system the laws of crystallization, with reference to the manner in which crystals are deduced in their several varieties from a primitive nucleus.

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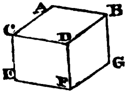
[*] Report of British Association for 1832, p. 428.

[†] From the Greek Πλησίος, *nearly alike*, and Μορφὴ, *form*.

[‡] From the Greek Ὅμοιος, *similar*, and Μορφὴ.

[§] From the Greek Δὶς, *twice* (in comp. σ omitted), and Μορφη.

No. 1.



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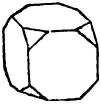

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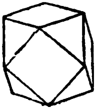
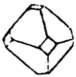


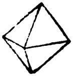
The relations between the different modifications of form in a mineral may be exemplified by taking a crystal of the fluor spar in one of the simplest of its natural forms, the cube, exhibited in the margin. Now it will be found on trial that the solid angles, A, B, C, D, &c., may all be removed by a knife with proper pressure, and thus the eight angles may be replaced by brilliant, flat, triangular surfaces, as in the next marginal figure, No. 2. The solid will then consist of fourteen sides instead of six; and each of the triangular sides may be enlarged at the expense of the square sides, by continuing the cleavage of increasing triangular planes, so as to form the succeeding figure, No. 3. At length, pursuing the separation of the crystal strata in the same direction, will be produced the remaining figures, Nos. 4 and 5, in the last of which no part of the original cube remains, every angle having been cut away so as to form eight new faces, constituting an octaedron, which is the primary form of the fluor spar.

A crystal of common salt, exhibiting the same cubic form with the fluor spar, differs from it in structure, for its angles cannot be separated so as to leave a smooth surface;

No. 4.



No. 5.

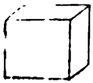


and the crystal will admit of cleavage or subdivision only in layers parallel to either or all its sides; so that a large cube can be separated into a number of small ones, but not reduced by cleavage to any other form: hence the cube is the primitive form or nucleus of the crystal of common or sea salt. In the same manner, Ponderous Spar, or sulphate of barytes, can be divided with regularity only so as to form right rhombic prisms; and Selenite, sulphate of lime, into right prisms: these therefore are the nuclei, or primitive forms of their respective crystals.

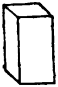
As the primitive nuclei of crystals may be developed by dissection, so it may be ingeniously shown how the varieties of crystals may be derived from the superposition of lamina on parallel surfaces, diminishing regularly in extent, so as at length to form the summit of a solid angle, or the edge of a line joining two angles. It is in this manner that Haüy, attributing to every crystallizable substance a primitive or simple form, ascertained by division, as before stated, or else inferred from a comparison with others already known, proceeds to derive, from his doctrine of increments and decrements, the various secondary forms that may be observed in different specimens of any given mineral.

According to the system of Haüy, all crystals are derived from five or six primitive forms. These are, (1.) the Parallelopiped, including the Cube, Rhomboid, and all their varieties; (2.) the Tetraedron; (3.) the Octaedron; (4.) the Hexaedral prism; (5.) the Rhomboidal dodecaedron; to which may be added, (6.) the Dodecaedron, with isosceles triangular faces.

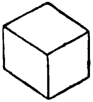
All solids having six sides, whose respective bounding lines taken in pairs are parallel with each other, and the opposite sides also equal and parallel, forming so many parallelograms, are termed Parallelopipeds. Such an arrangement of surfaces must obviously admit of some variety; and thus it may be perceived that the parallelopiped will include the cube, the square prism, the rhomboid, the right rhombic prism, and the oblique rhombic prism.



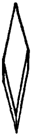
The *Cube*, as appears in the margin, has six square sides, all equal, like common dice; its proportions being invariable.



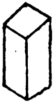
When a body is terminated by four equal oblong parallelograms laterally, and two square parallelograms at the ends, it is called a *Square Prism.*



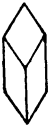
The *Rhomboid* has its opposite sides equal and parallel, but none of them are square, each having two obtuse and two acute angles, instead of four right angles, like the cube.



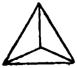
There are many varieties of rhomboids, characterized by the relative diversities of their corresponding angles; some rhomboids differing so little from the perfect cube that their real nature can only be ascertained by the measurement of their angles, others bearing but a very distant resemblance to it, as in the marginal figure, representing a very *Oblique Rhomboid.*



The *Right Rhombic Prism* bears the same relation to the square prism that the rhomboid does to the cube. In the square prism the angles are all equal, and are right angles; but in the right rhombic prism the sides or lateral planes meet alternately at angles greater or less than 90 degrees; but the terminal planes, or those at the extremities of the prism, form by their junction right angles.

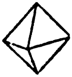


The *Oblique Rhombic Prism* differs from the preceding figure in the position of its terminal planes, which do not form right angles with the lateral planes, but are placed obliquely, so that the terminal and lateral planes meet at obtuse and acute angles alternately.

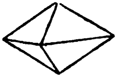


The *Tetraedron* is the simplest of all regular figures having plane surfaces. It is a solid included within four triangular planes, equal and similar, each of the three sides being of the same dimensions.

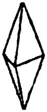
Some notice has been already taken of the octaedron, as the figure produced by the truncation of the solid angles of a cube. There are varieties, however, of this figure, arising from those of the eight planes by which it is terminated.



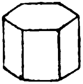
The *Regular Octaedron* has all its planes equal and similar triangles, each of their three sides being of the same length. All lines drawn through its centre from either angle to that opposite to it will be of equal length, or in other words it has three equal axes. This, however, is not the case with all octaedrons, some having one axis longer and some shorter than the other two.



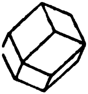
The *Obtuse Octaedron* differs from the former in having the line which forms the base of its triangular sides longer than those which meet at the apex, so that what may be termed its principal axis is shorter than its other axes.



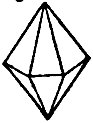
The *Acute Octaedron* will be perceived at once to be exactly the reverse of the foregoing, its base line being shorter than those which form the apex, and its principal axis longer than the others. These forms will obviously admit of several modifications, the nature of which may be comprehended without difficulty from what has been already stated.



The *Hexaedral Prism* derives its name from the number of its sides, which are similar parallelograms, not square, but oblong. They are six in number, and are called lateral planes, and as they meet the terminal planes, the latter are hexaedral and hexagonal; that is, they have six edges and six angles. The terminal planes are parallel with each other.



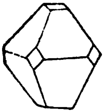
The *Rhomboidal Dodecaedron*, as its name implies, has twelve sides. These are all of similar form, each plane being a rhomb, of which the four bounding lines are of the same length, and the opposite lines are parallel, forming two acute and two obtuse angles in each plane. This figure is susceptible of numerous modifications, by the truncation of edges or angles.



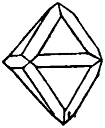
The *Dodecaedron with Isoscles Triangular Faces* is a figure having twelve equal triangular sides, differing from the octaedron in the number of its sides, and like that figure, admitting of modifications, according to the length of its principal axis.

The connexion of one form with another, or the transition from one to another, has been exemplified in the deduction of the octaedron from the cubic crystal of fluor spar. (See p. 276.) The following figures will serve in like manner to show what modifications are produced by the truncation of the angles and edges of an octaedron.

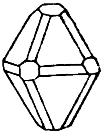
A



B



C



In fig. A, the angles only of the octaedron are truncated, in fig. B, the edges only, and in fig. C, both the angles and the edges. If we suppose the division of an octaedral crystal to be continued in the direction of the planes formed by the truncation of the edges, fig. B, in which the triangular planes of the truncated octaedron are separated from each other by narrow hexangular planes, a modification will be produced, exhibiting an increase of the hexangular planes, and reduction of the triangular ones, each however retaining its characteristic shape. By pursuing the division in the same direction, the original planes may be entirely removed, the triangular faces disappearing, and the hexangular ones being changed into rhomboedral surfaces. Such a series of modifications may be observed in the fluor spar, and more commonly in the red oxide of copper, serving to show how the rhomboedral dodecaedron may result from the replacement of the edges of the octaedron. But in neither of these minerals can the rhomboedral dodecaedron be obtained by cleavage from the truncated octaedron; for the laminæ of the crystal of fluor, or red oxide of copper, admit of separation only in directions parallel with the planes of the octaedron, that being the primitive form or nucleus of the crystals of the minerals in question.

In this transition from one form to another in the construction of crystals, it seems as if nature in the generation of each crystal assumed a central nucleus regular and constant in each species respectively, and on the several faces of that nucleus applied successive laminæ, all parallel and similar to each other, but diminishing regularly in extent, so as at length to terminate in a point forming the summit of a solid angle, or in a line forming the edge of the new crystal. Thus from a cubic nucleus, the formation of a rhomboidal dodecaedron may be supposed to take place, by the addition of successive laminæ on each face of the cube, which having a height denoted by 1, decrease gradually on their borders by a quantity also denoted by 1. So likewise a solid of twenty-four faces may be conceived to be formed from a cube by the application of laminæ, the thickness of which is denoted by 1, and the successive lateral decrements by 2, by 3, or any higher number, according as the pyramid is more or less elevated or depressed. An octaedron may in like manner be formed from a cubic nucleus by the successive application of laminæ having angular decrements; and by irregular, intermediate, or combined decrements, a vast variety of secondary forms may be produced from a very limited number of primitive nuclei. Hence in general, when the form of the nucleus of a mineral has been ascertained, nothing is more easy than to determine in what manner laminæ must be applied, and the law according to which they ought to decrease, in order to produce any given form of a crystal, the angles of which have been previously measured.

"But however ingenious this method of accounting for the diversity of crystals of the same substance may appear, and important as were the discoveries of the learned author, it must be admitted that it can only be regarded as an hypothesis which may assist us in our researches. Indeed it is not probable that nature should commence by the formation of the primitive crystal, in order to apply to it decremental laminæ. The bare inspection of crystals, which are often exceedingly small, and yet highly complicated, appears, on the contrary, to announce that all the forms have been produced by a single effort (*produites d'un seul jet*); while on the other hand, it may be observed that the large crystals are only regular assemblages of very small ones, often similar to the large crystals which they form, and sometimes different from them."[*] "These observations prove clearly that in general crystallization does not take place in nature according to the supposition adopted in the theory which has been given, but that the different crystals result rather from the sudden arrangement of the regular molecules among themselves, in the act of spontaneous solidification. For in studying the manner in which certain particles infinitely [indefinitely] minute, of a determinate form, may combine together, according to the number and the position of their faces, we may be led to conclude that the different polyedral figures to which they give rise depend on the number in which they are attracted together at the moment of crystallization. Thus, for example, it may be comprehended that cubic particles can only form complete cubes in those cases in which these molecules unite together in cubic numbers, as 8, 27, 64, 125, &c. With a little attention, we perceive, likewise, that regular octaedrons can only be formed when cubic molecules combine in one of the numbers of the series 7, 25, 63, 129, &c. Further, dodecaedrons with rhombic planes will be produced when the molecules are attracted together, in one of the numbers of the series 33, 185, 555, &c."*

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[*] Beudant Traité Élément. de Physique, p. 85.

These speculations might be pursued further, and it might be shown how other forms might be derived from cubic particles; but some figures would require for their production very extensive and complicated series of numbers of molecules; and hence this theory is objectionable, as wanting that simplicity usually observable in the laws of nature. There is more probability in the hypothesis ingeniously proposed by Dr. Wollaston, who considered the primitive particles as spheres, which by mutual attraction, assume that arrangement which brings them as near as possible to each other. When a number of similar balls are pressed together in the same plane, they form an equilateral triangle; and if, when thus arranged, they were cemented together, and the mass afterwards broken asunder, the lines in which separation would most readily take place, would form with each other angles of 60 degrees. A single ball placed any where upon such a stratum would touch three of the lower balls, and planes parallel to the sides of the figure thus formed would include a regular tetraedron. A square of four balls, with a single ball on the centre of each surface would constitute an octaedron; and on applying two other balls at opposite sides of the octaedron, the group would represent an acute rhomboid. The construction of the numerous varieties of figures which occur among crystals might be readily explained, by admitting the existence of oblate and oblong spheroidal molecules, as well as those of a globular figure.*

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* Beudant Traité Elément. de Physique, p. 86.

Crystals may not only differ one from another, as a rhombic prism from an octaedron or a dodecaedron, but one rhombic prism may differ from another; for, since the rhomb is characterized by having one of its adjacent angles smaller than a right angle and the other larger, it must be manifest that the one may consist of almost any number of degrees less than 90, and the other of any number below 180, which sum, however, must be the amount of the two angles taken together. For the four angles of the crystal collectively will be equal to four right angles, i. e., 90 × 4 = 360, or the number of degrees of a circle by which angles are measured. Thus the primitive form of carbonate of lime, calcareous spar, is a rhomboid whose faces are inclined at angles of 105° 5′, and 74° 5′, both together making 180°. Tourmaline has for its primitive crystal an obtuse rhomboid, the angle of which is 113° 10′, and in like manner other minerals have their peculiar and constant forms, the precise nature of which can alone, in many cases, be ascertained by measuring the angles of the crystal.†

Instruments for this purpose, called Goniometers, are chiefly of two kinds, the common and the reflective goniometer. The first and simplest of these instruments consists of a protractor, or semicircular scale, graduated from 0 to 180, with a small pair of compasses applied to it, destined to receive the crystal whose angles are to be measured.

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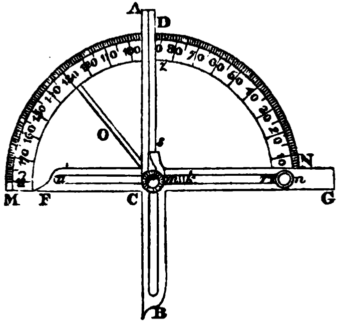
* Brande's Manual of Chemistry, 3d ed., vol. i. p. 16.

† Romé de l'Isle first called the attention of mineralogists to the remarkable fact, " that notwithstanding the irregular and changeable enlargements of certain faces, and the indistinct formation of the edges between these faces, the angle at which they meet always remains constant. This peculiarity affords one of the most distinctive characters which minerals possess; one by which the mineralogist is frequently led immediately to the determination of a species, and which, therefore, it is evidently of extreme importance he should ascertain with precision."—*Manual of Mineralogy, comprehendi the more Recent Discoveries in the Mineral Kingdom.* By Robert All F.R.S.E., M.G.S. 1834. p. xvi.



One arm of the compasses, F G, in the annexed figure, forms the diameter of the semicircular arc, and the other arm, A B, the radius of that arc, and this last being moveable on the pivot *m*, the two arms may be made to form any given angle with each other. The transverse arm is grooved or slit from *u* to *r*, except at *k*, where there is a little cross piece to strengthen it. By means of this slit, and the two pins *m* and *n*, this arm may be slid across the diameter of the arc, passing through the points zero and 180°. The pin *m* passes through a brass knob behind the arm F G, which is attached to the semicircle at N, and by the bar O. The arm A B has a groove from C to B, by means of which, when necessary, that arm may be shortened, by sliding it upwards. In order to use this instrument, it is merely requisite to place the crystal to be measured between the compasses, the arms of which being brought in exact contact with the planes forming the angle required, and the arm A B applied to the protractor, the value of the angle may be read off at the fiducial edge *z s*.

Though this instrument is serviceable to ascertain to a given extent the angles of crystals, it is far inferior in accuracy to the reflective goniometer, invented by Dr. Wollaston, the use of which, however, requires more skill and attention in the experimentalist. For an account of the latter, and of the method of employing it, we must refer the reader to the works of those who have treated the subject of crystallometry more fully than is consistent with the limits to which we are confined.*

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* A description of Dr. Wollaston's goniometer, with the mode of using it, illustrated by a diagram, will be found in Brande's Manual of Chemistry.

Among the latest and most important improvements in crystallographical mineralogy, is the introduction of crystallometrical systems: as the tesseral; the tetragonal, or square pyramid of Mohs; the rhombic, or oblong pyramidal, or prismatic of Mohs; the rhomboedral of Mohs, or hexagonal of Naumann; and the monoklinoedral, diklinoedral, and triklinoedral of the lastmentioned writer. Some notion may perhaps be formed of the nature of these distinctions from the following representation:

"If we conceive a square steeple with all the four sides of the walls and roof exactly alike, so that every slope and face which occurs on one side occurs similarly on the other three, we have before us a form belonging to the square pyramidal system. If, instead of this, we imagine a house of which the two ends are like each other, and the two sides also precisely like each other, but different from the former, this will belong to the oblong prismatic or rhombic system. If again we conceive a triangular pillar, as an ancient tripod, its three sides being similarly cut and ornamented, this will belong to the rhomboedral system.* In fact, its three faces may be terminated by slopes, which may meet and form an apex, resembling in all respects the apex of a rhomboedron. And if each of its three faces be formed into an edge, by planes sloping to the right and left, the form may be thus converted into a six-sided pillar with no loss of its regularity.

"If we conceive the form of the house of which we spoke, as representing the prismatic system to be made less regular, by sloping its end walls in the direction of one end, we have the monoklinoedral system, and if the side walls slope also, we may have thus the diklinoedral and triklinoedral forms.

"The tesseral or tessular system includes the forms which are derived from the regular solids of geometry, the cube, the octaedron, the dodecaedron.

"This distinction of different kinds of forms is one founded on the most general relation of their parts, and regulated by the degree and

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vol. i. pp. 10—13; or in Mrs. Lowry's Conversations on Mineralogy, 2d ed., vol. i. pp. 71—75.

* The rhomboedral and rhombic systems are quite distinct. A rhombic prism has its *base* a rhomb; a rhomboedron has *all its sides* equal rhombs.

kind of their symmetry. The claim of priority in introducing this classification of forms has been a subject of controversy between Prof. Mohs and Prof. Weiss. However this question may be decided, the merit of this valuable simplification rests between them; and all must allow the propriety with which Prof. Naumann, of Freiberg, the author of the best recent system of crystallography, has dedicated his work '*to Mohs and Weiss, the Coryphæi of German Crystallographers.*' "[*]

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[*] Report of Brit. Assoc. for 1832, pp. 328, 329. For a further explanation of the crystallographic system of Prof. Mohs, see Allan's Manual of Mineralogy, Introd., pp. xviii. xix.

GEOLOGY.

VIDI EGO QUOD FUERAT QUONDAM SOLIDISSIMA TELLUS
ESSE FRETUM. VIDI FACTAS EX ÆQUORE TERRAS,
ET PROCUL A PELAGO CONCHÆ JACUERE MARINÆ.

Ovidii Metamorphos., lib. xv.

GEOLOGY.

Geology is a science exclusively of modern origin, presenting to our notice a series of facts and deductions resulting from researches almost entirely of a recent date. It relates to bodies, multitudes of which must necessarily have attracted the attention of mankind in all ages and countries, and many of whose properties have been frequently and closely investigated; but it is the peculiar purpose of this branch of philosophy to develop the relations of natural substances as contributing to form the terrestrial globe; and hence the interest or importance of any given object, as a block of granite or marble, a nodule of flint, a petrified shell, a fragment of fossil bone, or any other natural production, is not decided on by the geologist with reference to its chemical composition or peculiar structure, simply considered;

Baron Fourier; and many facts have been brought forward in support of it by Cordier, R. W. Fox, and other writers. There is nothing extravagant in the length of time during which Whiston supposed the process of cooling to have been going on in the earth, for in 1680 a comet passed so near to the sun that, from the calculations of astronomers, it must have acquired a temperature two thousand times that of red-hot iron, and would require fifty thousand years in cooling. Hence if the earth had been a comet, its nucleus would have been still burning, since the epoch of its access to the sun is supposed not to have exceeded six thousand years.*

Benedict de Maillet, who held the office of French Consul in Egypt, and was the author of some philosophical works, was a speculator of a different order from the preceding. About the middle of the last century appeared one of his productions, entitled "Telliamed" (the anagram of his name), containing some geological, or rather cosmogonical theories, abundantly absurd and extravagant, but deserving of some notice, as being founded on accurate and extensive observations on existing phenomena. This gentleman, in the course of his travels, remarking the occurrence of sea-shells and other marine remains on the summits of the highest mountains, inferred that the present continents were entirely formed beneath the surface of water, which must have originally covered the whole earth; that ever since the first appearance of islands in the universal ocean, the waters have been gradually decreasing; in proof of which he instances the formation of the Delta of Egypt, at the mouth of the Nile, and of similar tracts in other parts of the world, and the alleged extension of the sea-shores in various places. He supposed this gradual decline of the sea to be yet in progress; and his opinions so far have been admitted by many other geologists. But De Maillet not only conceived the whole globe to have been for many thousands of years covered with water, but he further alleged that this water gradually retreated, that all the land animals were originally denizens of the sea, that man himself commenced his career as a fish, supporting his reveries by adverting to stories of sirens, mermaids, tritons, satyrs, and suchlike monsters; and asserting that even now animals may be found in the ocean half-human and half-fish, but whose descendants will in time become perfect men and women. Strange and inconsistent as are these speculations, they have been revived and extended by more recent theorists. They suppose that the earth was originally in a fluid state, that the primitive fluid gave existence to animals, which were at first only of the most simple kind, as the *monas*, and other infusory and microscopic species; that in process of time, and by assuming different habitudes, the races of animals became complicated, and at length appeared in that diversity of form and character which we now perceive. By means of those various races of animals, part of the waters of the sea have gradually been converted into calcareous earth; while the vegetables, concerning the origin and metamorphoses of which these writers choose to be quite silent, have, on their part, converted a portion of the same water into clay: these two earths, on being deprived of the characters which vitality had impressed on them, are, by an ultimate analysis, resolved into silex; and hence the reason that the oldest mountains are more siliceous than the rest. All the solid parts of the earth, therefore, owe their existence to life, and without life the globe would still be entirely liquid.*

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* Lettres sur les Révolutions du Globe, par D. Alex. Berthier. 3d edit. Paris, 1828. 24mo. pp. 11, 12.

Other theorists ascribe the origin of the earth to fragments which have fallen successively from the heavens, in the manner of aërolites, or meteoric stones; and thus account for the relics of strange monsters, which they suppose to have been the inhabitants of unknown worlds.†

One bold speculator imagines the earth to be hollow, and places within it a magnetic nucleus, which is transported from one pole to the other, by the attraction of comets, carrying with it the centre of gravity, and the mass of waters on the surface, and thus alternately drowning either hemisphere.‡

A few years ago, an American officer named Symes asserted that the earth is not only hollow, but also that the interior is inhabitable, or at least accessible; for he alleged that an opening leading to it exists somewhere in the northern hemisphere, and he proposed to explore it.

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* V. La Physique de Prodiee. Leips. 1801. p. 106; and Telliamed, vol. ii. p. 169. M. de Lamarck has, of late years, developed this system most extensively, and displayed much ingenuity in defence of it, in his Hydrogeologie, and Philosophie Zoologique. Cuvier's Theory of the Earth, p. 41.

† See MM. de Marschall's Researches concerning the Origin and Development of the existing Order of the Terrestrial Globe. Giessen, 1802.

‡ See Bertrand on the Periodical Renewal of the Terrestrial Continents. Hamburgh, 1799.

It is unnecessary to detail the reveries of Burnet, Woodward, and other writers of less note, who proposed their various and discordant explications of the origin and structure of the earth.

But while so many philosophers were busily employed in endeavouring to erect systems of cosmogony on the basis of their own most imperfect knowledge of the nature of mineral bodies, or drew their ephemeral theories solely from imagination, there were some who more wisely applied themselves to the observation of nature, and to the collection of correct information relative to the productions of the mineral kingdom in general, and especially concerning those fossils which exhibit traces of having originated from organization. Bernard Palissy, a potter of Saintes, towards the end of the sixteenth century, is said by Fontenelle to have been the first who ventured to assert in Paris, in opposition to the prevailing opinion, that petrified shells were the remains of testaceous animals that had formerly lived in the sea, and that all these were not deposited at the universal Deluge. He wrote on the Origin of Springs from Rain-water, and other scientific works; and he had the merit of displaying much juster views of the operations of nature than most of his contemporaries, though his ideas met with a very faint reception among his contemporaries. Similar notions were advocated by Nicholas Steno, a Dane, who became professor of anatomy at Padua, in Italy, in 1669; and Hooke and Ray, in England, distinguished themselves by opposing facts to visionary theories.

Leibnitz, in his Protogæa, published in 1680, advanced the bold hypothesis, that the earth was originally a burning luminous mass, the gradual refrigeration of which produced the primitive rocks, forming at first a solid crust, and this being ruptured, owing to irregular contraction, the fragments fell into the universal ocean formed by the condensation of vapours on the surface of the globe. He proceeds to trace the production of inundations, convulsions, and attrition of solid matter, by its subsequent deposition constituting the various kinds of sedimentary or stratified rocks. Hence, he observes, may be conceived a double origin of primitive masses; 1. By cooling after igneous fusion; 2. By re-concretion from aqueous solution.* "Here," says Mr. Conybeare, "we have distinctly stated the great basis of every scientific classification of rock formations."†

The grand feature of the theory propounded by Leibnitz, relative to the candescent state and gradual cooling of the earth, was adopted not only by Whiston, as already mentioned, but likewise more recently by Buffon, Deluc, and other theorists. Among those men of science who contributed to the improvement of geology, by their researches into the actual structure of the earth's crust, was Tilias, a Swede; who, aware of the importance of an exact knowledge of mineral bodies, published in 1750 several topographical descriptions illustrative of the geology of certain districts in Sweden. He was followed by Lehman, a German mineralogist, director of mines in Prussia, who, in an Essay towards a Natural History of the Strata of the Earth, 1756, proposed a division of mountains into those formed before the creation of animals, and containing no fragments of other rocks; mountains which were derived from the partial destruction of the primary rocks by a general revolution; and those which resulted from local revolutions, and in part from the Noachian Deluge. Many other writers now appeared, who advantageously directed their attention to the investigation of particular topics connected with this subject; as the causes and phenomena of earthquakes and volcanos, the formation of deltas or low tracts at the mouths of rivers, the actual structure and position of mineral strata, and the description of fossil remains of animal or vegetable origin. Among those who rendered important services to the cause of science by advancing general views of the theory of the earth, were Dr. James Hutton, of Edinburgh, and Professor Werner, of Freyberg, in Saxony. These celebrated philosophers produced systems, in one respect, diametrically opposite to each other; for while Hutton attributed the formation of the older rocks entirely to the agency of fire, Werner insisted that they originated from solution in a liquid. The German geologist, however, deserves the credit of having directed the attention of his pupils to the constant relations of mineral groups, and their regular order of superposition; distinguishing the classes of primary rocks, or those destitute of organic remains, as granite and gneiss; transition or secondary rocks, formed from the disintegration of the preceding, and occasionally exhibiting traces of organic remains, as greywacke, a mechanical compound of agglutinated fragments; floetz or tertiary rocks, including the coal strata, chalk, and freestone, some of which abound in organic relics; and besides these alluvial strata and volcanic rocks, the latter of which he seems to have regarded as of little importance, for he asserted that in the primeval ages of the world there were no volcanos. The great merit of Hutton consists in his having demonstrated the igneous origin of basalt, and other trap rocks; the high probability that granite is derived from the same source; and that the other primary non-fossiliferous rocks have been more or less subjected to the agency of fire. "The ruins of an older world," said Hutton, "are visble in the present structure of our planet, and the strata which now compose our continents have been once beneath the sea, and were formed out of the waste of pre-existing continents. The same forces are still destroying, by chemical decomposition or mechanical violence, even the hardest rocks, and transporting the materials to the sea, where they are spread out, and form strata analogous to those of more ancient date. Although loosely deposited along the bottom of the ocean, they become afterwards altered and consolidated by volcanic heat, and then heaved up, fractured and contorted."*

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* "Unde jam duplex origo intelligitur primorum corporum, una, cum ab ignis fusione refrigescerent, altera, cum reconcrescerent ex solutione aquarum."

† Progress, Actual State, and Ulterior Prospects of Geological Science, in Report of British Association for 1832, p. 368.

The theory of Hutton was admirably illustrated, and ably supported, by Professor Playfair, of Edinburgh, while it was assailed by Murray, Kirwan, Deluc, and others, a violent controversy being maintained between the partizans of Werner, who were called Neptunists, as ascribing the formation of all rocks to water; and those of Hutton, styled Vulcanists because they attributed the original formation of rocks to fire. The Neptunists, for a time, constituted by much the more numerous party; but in the course of these discussions, it was at length perceived that speculation had, on both sides, been carried further than was warranted by the extent of existing information; and that while neither the theory of Werner, nor that of Hutton, could be considered as affording an explanation of all the phenomena, or making near approaches to perfection, there were many points with respect to which the researches and observations of both these philosophers contributed to the extension of our knowledge, and the improvement of the science.

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* Lyell's Principles of Geology, 3d ed., 1834, vol. i. pp. 88, 89; from Hutton's Theory of the Earth.

"A new school at last arose, who professed the strictest neutrality, and the utmost indifference to the systems of Werner and Hutton, and who were resolved diligently to devote their labours to observation. The reaction, provoked by the intemperance of the contending parties, now produced a tendency to extreme caution. Speculative views were discountenanced; and through fear of exposing themselves to the suspicion of a bias towards the dogmas of a party, some geologists became anxious to entertain no opinion whatever on the causes of phenomena, and were inclined to scepticism, even where the conclusions deducible from observed facts scarcely admitted of reasonable doubt.

"But although the reluctance to theorize was carried somewhat to excess, no measure could be more salutary at such a moment than a suspension of all attempts to form what were termed *theories of the earth*. A great body of new data was required, and the Geological Society of London, founded in 1807, conduced greatly to the attainment of this desirable end. To multiply and record observations, and patiently to await the result at some future period, was the object proposed by them; and it was their favourite maxim, that the time was not yet come for a general system of geology, but that all must be content for many years to be exclusively engaged in furnishing materials for future generalizations. By acting up to these principles with consistency, they in a few years disarmed all prejudice, and rescued the science from the imputation of being a dangerous, or at best but a visionary pursuit."*

One train of research which was now pursued with great ardour, and which contributed much to the improvement of science, was respecting the nature of the organic remains, which were found imbedded in various strata in different parts of the world. Cuvier, the celebrated anatomist and zoologist, professor of natural history at Paris, acquired great distinction by the number, accuracy, and importance of the discoveries which he made relative to the generic and specific characters of the animals, fragments of whose bones, and other constituent parts, occurred to notice in the course of his long and laborious investigations. He ascertained that numerous living beings of different classes, which have no existing analogues, once inhabited the surface of the globe; and that the relative priority of the several strata might, to a certain extent, be inferred from the characters of the organic remains included in them. Among the recent cultivators of this branch of science besides Cuvier, may be named Alex. Brongniart, Lamouroux, Lamarck, Deshayes, Marcel de Serres, Brocchi, Goldfuss, Parkinson, Buckland, Conybeare, J. S. Miller, Mantell, and Lonsdale, who devoted their attention chiefly to fossilized animal remains; and Adolphe Brongniart, Witham, Lindley, and W. Hutton, whose investigations have been especially directed to botanical oryctology. The results of their researches relative to these subjects, and those of other geologists concerning the mineralogical structure and position of rocks and mountains, and the modifying influence of existing causes on the surface of the earth, have greatly contributed to the augmentation of our knowledge of the nature and arrangement of the superficial strata of the planet on which we dwell, which must be regarded as the only sure foundation of a true system of geognosy, which may verify or overturn the conjectural speculations of those philosophers who wrote during the infancy of the science.

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* Lyell's Principles of Geology, vol. i., pp. 102, 103.

The highly interesting nature and relative importance of the discoveries of modern geologists have been most eloquently unfolded by two distinguished writers, who have themselves contributed in no small degree to extend the boundaries of knowledge.

"When we compare the result of observations in the last thirty years, with those of the three preceding centuries, we cannot but look forward with the most sanguine expectations to the degree of excellence to which geology may be carried, even by the labours of the present generation. Never, perhaps, did any science, with the exception of astronomy, unfold, in an equally brief period, so many novel and unexpected truths, and overturn so many preconceived opinions. The senses had for ages declared the earth to be at rest, until the astronomer taught that it was carried through space with inconceivable rapidity. In like manner was the surface of this planet regarded as having remained unaltered since its creation, until the geologist proved that it had been the theatre of reiterated change, and was still the subject of slow but never-ending fluctuations. The discovery of other systems in the boundless regions of space was the triumph of astronomy—to trace the same system through various transformations—to behold it at successive eras adorned with different hills and valleys, lakes and seas, and peopled with new inhabitants, was the delightful meed of geological research. By the geometer were measured the regions of space, and the relative distances of the heavenly bodies—by the geologist myriads of ages were reckoned, not by arithmetical computation, but by a train of physical events—a succession of phenomena in the animate and inanimate worlds—signs which convey to our minds more definite ideas, than figures can do, of the immensity of time."*

"By the discoveries of a new science (the very name of which has been but a few years ingrafted on our language), we learn that the manifestations of God's power on earth, have not been limited to the few thousand years of man's existence. The geologist tells us, by the clearest interpretation of the phenomena which his labours have brought to light, that our globe has been subject to vast physical revolutions. He counts his time, not by celestial cycles, but by an index which he has found in the solid framework of the globe itself. He sees a long succession of monuments, each of which may have required a thousand ages for its elaboration. He arranges them in chronological order, observes on them the marks of skill and wisdom, and finds within them *the tombs of the ancient inhabitants of the earth.* He finds strange and unlooked-for changes in the forms and fashions of organic life during each of the long periods he thus contemplates. He traces these changes backwards through each successive era, till he reaches a time when the monuments lose all symmetry, and the types of organic life are no longer seen. He has then entered on the dark age of nature's history; and he closes the old chapter of her records.

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* Lyell's Principles of Geology, vol. i. pp. 106, 107.

This account has so much of what is exactly true, that it hardly deserves the name of figurative description."*

FIGURE AND MAGNITUDE OF THE EARTH, ITS MEAN DENSITY, SUPERFICIAL CONFORMATION AND STRUCTURE.

Before we proceed to describe the present state of the crust of the earth, and investigate the probable causes of its origin and structure, with the nature of the strata or more irregular masses of which it is composed, it will be requisite to notice those facts concerning the general figure, dimensions, and density of the terrestrial globe, and of the contour of its surface, as a body of land and water, for a knowledge of which we are indebted to the researches of astronomers and geographers.

That the figure of the earth is spherical, or rather spheroidal, though a matter of dispute among ancient philosophers, and still disbelieved by the vulgar, is now admitted as an incontestable truth by all well-informed persons. The curved surface of the sea when viewed from the shore, and the observation that the upper rigging of an approaching ship becomes visible to a distant spectator before the hull comes in sight, while the hull first disappears when the vessel is receding, prove that the object in question must be moving in the circumference of a great circle. A similar conclusion may be drawn from the changing aspect of the heavens to an observer travelling from north to south. For though the stars and the constellations they form will be found to maintain the same relative positions with respect to those around them, and the points on which the celestial dome appears to revolve remain unaltered, yet the angle which its axis of revolution forms with the horizon continually lessens; and thus any star, which at the place whence he started, seemed to the observer to have reached its greatest elevation to the south of the point directly above his head, now that he has altered his position, will appear, when highest, on the north of that point; clearly indicating that his path on the earth's surface has not been a right line, but a curve, of which the convexity is turned towards the sky, corresponding, in fact, more or less, with a meridian of longitude. The appearance of the moon when eclipsed, likewise furnishes demonstrative proof of the spheroidal figure of the earth, for lunar eclipses are caused by its circular shadow intercepting the light of the sun from the moon's disk.

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* Discourse on the Studies of the University, by Adam Sedgwick, M.A., F.R.S., Woodwardian Professor, and Fellow of Trin. Coll. Camb., 1834, pp. 25, 26.

It has been found, however, both from astronomical and geodesical observations, that the earth is not a perfect sphere, but that its figure is that of an oblate spheroid, or such a solid as would be formed by the revolution of a fluid mass in open space. Huygens and Newton deduced the real figure of the earth from the doctrine of central forces of bodies revolving in circles, and their conclusions were subsequently verified by actual measurements of degrees of the meridian in various latitudes. It appears, however, that though the polar diameter of the earth is certainly smaller than its equatorial diameter, the exact difference between them has not yet been accurately ascertained. It has been estimated by some at $\frac{1}{305}$ part of the equatorial axis, by others at $\frac{1}{310}$ part; but Professor Wallace says, "We may assume, without sensible error, that the equatorial axis is to the polar as 334 to 333; the difference, therefore, of the semiaxes, compared with the equatorial radius, will be 1 part in 334. The fraction of $\frac{1}{334}$, that is, the difference of the semiaxes divided by the equatorial radius, is called the *compression* of the earth at the poles."*

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* Murray's Encyclopaedia of Geography, 1834, part ii. b. i. ch. 19, p. 128.

"As the earth has a movement of rotation about its axis, all its parts will be animated with a certain degree of centrifugal force, which must be more or less considerable as the parts approach or are distant from the axis. Under the equator will be the points of greatest distance from the axis, and the centrifugal force directly opposed to that of weight or gravitation, ought to reduce the latter there more than at any other place; and at parts intermediate between the poles and the equator, the diminution of weight ought to become less sensible, in proportion as they are nearer the poles. At either pole the centrifugal force will vanish, and bodies will have the same weight as if the earth were at rest.

"As gravity must be normal at the surface of the sea, and as it is the resultant of terrestrial attraction and centrifugal force, it will be obvious that it must vary at different places; and that if the earth was originally a fluid, it could not, in consequence of its rotation, preserve the form of a sphere, but that it must assume that of a flattened spheroid, which would be generated by

The determination of the figure of the earth leads to conclusions respecting its mean density, which also has within certain limits been sufficiently ascertained. Sir Isaac Newton, reasoning on the supposition of uniform density in the earth, estimated its compression at the poles as $\frac{1}{230}$ of its diameter. Now, since experiment has demonstrated that the compression is less, amounting at most to $\frac{1}{305}$, it may be concluded from the observations of Clairault, that if the earth is a spheroid of equilibration, it is denser in the interior than at its surface; and from the experiments of Dr. Maskelyne and Mr. H. Cavendish,* it has been inferred that the mean density of the earth is about five times that of water, and therefore double that of the substances which compose the crust of the earth, collectively considered.

Since then the mean density of the terrestrial globe is so much superior to that of its superficial strata, it follows that the interior or central parts must be composed of more dense materials than the exterior. On a subject so open to speculation as the constitution of the nucleus of the earth, a variety of conjectures, as might be expected, have been hazarded. Diderot endeavoured to explain terrestrial magnetism and other phenomena, by supposing the internal mass to be a vitrified body, on which as a centre the exterior shell revolved, producing by friction the same effect as the cushions on the cylinder of an electric machine. The superior density of the interior parts of the earth compared with the exterior, has induced some to conclude that the nucleus of the earth must consist of some substance or substances naturally possessing high specific gravity, like certain of the metals. "It can be neither gas nor water," says Dr. Bertrand, "which constitutes the interior mass, nor yet the heaviest stony substances with which we are acquainted, for on this last supposition, the entire spheroid would have but one-third or one-fourth of the weight which has been attributed to it from calculation; therefore it must be composed of matter as ponderous as the heaviest metals."†

This ingenious speculator, however, in reprobating the hypothesis of

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the revolution of an ellipsis round its smaller axis. This also is demonstrated by experience, and that the flattening at the poles renders the axis 1-310th less than the diameter at the equator."—*Francœur Traité de Mécanique Élémentaire*, 1825, pp. 287, 288. See Book of Science, part i. pp. 47, 48, 51—54.

* See Book of Science, part i. p. 28.

† Lett. sur les Rev. du Globe, p. 40.

a fluid or gaseous nucleus of the earth, has entirely neglected the consideration of the relative compressibility of elastic fluids compared with bodies which on the surface of the earth possess superior density. Mr. Colebrooke, in a paper published in Brande's Journal of Science, advanced some curious and interesting speculations on the internal portions of the earth, designed to show that they may consist of air and water, reduced by compression to extraordinary degrees of density. He observes that "At a certain assignable depth water may have a density greater than that of those solids which are most abundant in the crust or shell of the terrestrial globe. Hence it would follow that water at a very great depth would be capable of floating bodies which at the surface sink by their superior weight, provided density and specific gravity increase much less rapidly in the solid than in the liquid, under corresponding degrees of compression. Let a sphere now be supposed having the same mean temperature of its mass, and exclusively composed of gas; for instance, atmospheric air. It can be conceived that this gas, more compressible than a liquid, may in obedience to the power of gravity, acting directly and likewise mediately, by superincumbent pressure, be so distributed in the sphere, as that the density and consequent weight of the compressed gaseous fluid at the centre of the sphere, and to a certain extent around, will be greater than that of the liquid in a like position within the globe before mentioned. It would be capable then of sustaining in a liquid form water introduced into it. Let these suppositions be combined, and a ball be next imagined, composed of a gaseous fluid, and of a liquid with solids interspersed. It is easy to conceive the relative compressibility of these substances, and the actual compression of them, to be such that the entire portion around the centre may be occupied by highly condensed gas, encompassed by a liquid mass, which is pervaded by a gaseous fluid, both decreasing in density upwards; and beyond the liquid surface surrounded by an atmosphere consisting of gas penetrated by aqueous vapour. Solid substances sparingly scattered in such a fluid ball would float at a great depth; but the magnitude of cohesive masses, and the abundance of them, may be imagined such that they may be fast locked and fixed together, in the manner of field-ice, at the same time that the weight of them is such as would float them were they loose, like an iceberg, with a relatively small portion of the floating mass emergent. In a word, a solid crust might exist, sustained by the water in which it is immersed, at the same time that the irregular and uneven surface of the cohesive mass emerges in part, while other portions are submerged."*

Sir John Leslie instituted some important experiments on the compressibility of different kinds of matter, from which he drew very remarkable conclusions, deeply affecting the subject under consideration. He computed that air under the law of uniform condensation would become as dense as water at the depth of 33¾ miles, and that at a further depth of 163¼ miles, it would acquire the density of quicksilver. Water at the depth of 93 miles would be compressed to half its former bulk; and at the depth of 362½ miles would be as dense as quicksilver. Even marble itself, subjected to its own pressure, would become twice as dense as before, at the enormous depth of 287¾ miles. Air, however, from its rapid compressibility, would acquire the same density with water, sooner than the latter fluid would reach the condensation of marble. If we calculate for a depth of 395⅝ miles, or about a tenth part of the radius of the earth, we shall find that air would attain the astonishing density of 101960 billions; while at the same depth water would attain but the density of 4.3492, and marble only that of 3.8025. At the centre of the earth air would reach the inconceivable density denoted by 764, with 166 ciphers annexed; while water would be condensed 3,009,000 times, and marble acquire the density of 119.

"Such are the prodigious results deduced from the law of gravitation, even supposing the structure of the globe were uniform. But if we take into the estimate the augmented power from condensation, the numbers would become still more stupendous. It follows, therefore, that if the great body of our earth consisted of any such materials as we are acquainted with, its mean density would very far surpass the limits assigned by the most accurate investigations. It seems, therefore, to follow conclusively, that our planet must have a very widely cavernous structure, and that we tread on a crust or shell, whose thickness bears but a very small proportion to the diameter of its sphere. Physical science can extend her prospects to the farthest verge of possibilities, but chemistry, even in its present advanced stage, fails altogether in aiding inquiry; and the various hypotheses framed by geologists are built with such scanty and slender materials, as to furnish no safe guidance through those boundless speculations. It is evident that immense compression would totally derange the powers of elective attraction, and change the whole form and constitution of bodies. When air becomes denser than gold, it is hard to conjecture what transmutations this plastic fluid must undergo. The bowels of the earth may contain substances thus transformed, bearing no longer any resemblance to their aspect on its surface.

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* *On Fluidity; and an Hypothesis concerning the Structure of the Earth.* Journ. of Science, vol. ix. pp. 52—61.

"But since an absolute void is inadmissible, the vast subterranean cavity must be filled with some very diffusive medium, of astonishing elasticity or internal repulsion among its molecules. The only fluid we know possessing that character is LIGHT itself, which, when imbodied, constitutes *elemental heat* or *fire*." Prof. Leslie proceeds to compare the velocity of light with that of air, and hence infers that "its modulus of elasticity must amount to the stupendous column of 3200 billions of miles, an extension which is 889 times greater than the diameter of the orbit of Uranus, the most distant of the planets yet discovered. Only such surpassing powers of repulsion would appear at all adequate to balance the cumulative mass of compression, and restrain the condensation of our globe within moderate limits. We are thus led, by a close train of induction, to the most important and striking conclusion. The great central concavity is not that dark and dreary abyss which the fancy of poets had pictured. On the contrary, this spacious internal vault must contain the purest ethereal essence, *light*, in its most concentrated state, shining with intense refulgence and overpowering splendour."*

Such is the truly brilliant theory announced by Sir J. Leslie, relative to which Mr. Conybeare remarks, that the calculations on which it is founded are formed on the assumption that the modulus of elasticity of air, water, &c., is invariable, however greatly the pressure may be increased, a conclusion rendered questionable by the experiments of Faraday, on the condensation of gases, and which does not take into the account variations of temperature. Other objections might be advanced, which would apply to the hypotheses of both Colebrooke and

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* Leslie's Elements of Nat. Philos., vol. i. note i. pp. 450—453.

Leslie; but they would rather tend to show the difficulty of the subject, than to furnish ground for the erection of a more probable theory.

Observations relative to the temperature of the earth, and the probable sources whence it is derived, might be expected to lead to some reasonable conclusions relative to its central structure and composition. This subject may be regarded as appertaining more directly to the science of pyronomics than to geology, and it has accordingly been generally noticed in the preceding volume of this work;* but it is so intimately connected with the topics under discussion, as to require more particular attention.

That the internal parts of the earth are more highly heated than its surface, and that their temperature depends on other causes than the influence of the sun's rays, may naturally be inferred from the phenomena of volcanos and thermal springs, which have in some degree attracted the attention of philosophers in early times; but the doctrine of central heat, adopted to account for these and other analogous occurrences, has recently derived strong confirmation from experiments and observations, instituted for the express purpose of ascertaining how far it is consistent with the general economy of nature.

In 1671, Cassini, the first distinguished astronomer of that name, noticed that in the caves under the Observatory at Paris, the temperature had remained unaltered during a whole year; and in 1730, Labire made a similar observation. Forty years later the Count de Cassini first perceived the full importance of this phenomenon; and in 1771, he commenced a series of experiments for the purpose of elucidating it. At length, on the 4th of July, 1783, he, in conjunction with Lavoisier, placed in the caves of the Observatory a very sensible thermometer, so arranged as to show the slightest variations of temperature that might take place. It was fixed 30.6 yards below the surface, and imbedded in sand; and the observations of Cassini himself, with those subsequently made by Bouvard for thirty-two years, showed that during more than half a century the temperature of the caves has remained permanent at 11°.82 of the centigrade thermometer, the slight oscillations which occurred never amounting to more than 25 centièmes of a degree above or below 11°.82, and being apparently owing to accidental causes. The mean annual temperature of the air at Paris is only 10°.6, so that the constant temperature of the earth there 30.6 yards beneath the surface, exceeds it by 1°.2 centig., or 2°.16 of Fahrenheit. Hence it appears that the depth corresponding to an augmentation of temperature amounting to 1°, is about 25⅔ yards; and admitting that the temperature increases uniformly with the depth, the heat must be equal to that of boiling water at the depth of 2542 yards below Paris. Observations thus exact and long continued have unfortunately been made only at the Parisian Observatory, but from the nature of the results it may be inferred, that this stability of subterranean temperature, is not an accidental phenomenon, but depends on general causes, and therefore it may be concluded that in all places, at a given depth beneath the surface of the earth, there is a certain point at which the temperature remains constantly the same, being uninfluenced by those causes which may affect the surface.

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* See Book of Science, part i. pp. 292—296; 2d ed., pp. 298—302.

The series of such points of invariable temperature around the globe may be termed the invariable stratum, at which the influence of all those alternations of heat and cold, occasional or periodical, which might act on the superior soil, would be extinguished. This stratum, however, cannot be considered as forming a regular curve, or maintaining a constant distance from the surface; for its depth and conformation must be affected by the nature of the surface, as consisting of land or water, and as being diversified by plains, mountains, and valleys, and composed of materials more or less dense and compact.

A few observations only have been made relative to the variations of temperature which take place in the space between the surface and the invariable stratum. So far as they go, however, they tend to show that the influence of the solar heat prevails in the summer months, and that of central heat in the winter, as might be expected.

But the most important observations are those which have been made on the temperature of the earth below the invariable stratum. The prevalence of heat in mines had been noticed and variously accounted for by philosophers, long before it was made the subject of direct experiment. Gensanne appears to have first discovered that the temperature of the earth increases with the depth below the surface, by means of thermometrical observations instituted in the lead-mines of Giromagny, near Befort, in 1740; and in 1785, corresponding experiments were made by Saussure, in a mine at Bex, in the canton of Berne. In 1791, the subject occupied the attention of Humboldt, who made an extensive and interesting series of experiments in the mines of Freyberg. In 1802, D'Aubuisson revived the important investigation, and since that time observations have been multiplied in the principal mines of Europe, in France, in Germany, and in England, while Humboldt proceeding on his memorable scientific voyage in 1798, examined the temperatures of the mines of America to the depth of 522 metres.

M. Cordier, in 1827, published an interesting memoir, on the temperature of the earth (in *Mémoires du Muséum d'Histoire Naturelle*), in which he collected the observations of others, together with his own, and having classed and arranged them, drew from them some interesting general conclusions. He ascertained that after making due allowance for the heat in mines arising from the presence of miners, the combustion of lamps, and communication with the atmosphere, the following results were established:

1. Below the invariable stratum, where the oscillations of surface heat are extinguished, the temperature remains perfectly constant for given depths, without any variation for several years. 2. That in all places where observations have been made below the invariable stratum, the temperature always goes on increasing with the depth. 3. That the ratio of the augmentation of temperature, in descending below the invariable stratum, is different for different places. M. Cordier considers, that from 25 to 30 metres' depth may be assumed approximately as corresponding with an increase of temperature, amounting to 1 centesimal degree; and therefore 1° of Fahrenheit may answer to about 15 yards. On the last supposition of 1° F. additional for every 15 yards of vertical descent, it must follow that at the centre of the globe the temperature would rise to 3500° of Wedgwood's pyrometer. The temperature of 100° W., which would be sufficient for the fusion of lavas and most kinds of rocks, would be found at the depth of about 120 miles. It is, however, uncertain what may be the mean thickness of the solid crust of the earth; and Cordier imagines that it may not exceed 60 miles. Hence a strong presumption arises in support of the inference, that the consolidation of the exterior crust is the effect of a gradual cooling.

If this is the case, the consolidation must have commenced at the surface, and proceeded towards the interior; and therefore, contrary to the received opinions of geologists, the primitive rocks are more ancient in proportion as they are nearer the surface. It follows also, that the strata ought to be arranged in the order of fusibility, or nearly so, some allowance being made for the interruption of this order, owing to the rapidity of cooling at first, and to the influence of chemical affinity on the vast mass of the globe.

Another necessary consequence of the hypothesis is, a contraction of the dimensions of the earth, through the diminution of its temperature; causing subsidence and approximation of the exterior crust, and consequent dislocation of its parts. This may account for the numerous cracks and fissures, and the irregularity of the disposition and inclination of the superior strata. But the subsidence not taking place regularly, would not produce a general, or very extensive change of level, though it might be sufficient to explain certain phenomena not easily accounted for otherwise: such as the apparent secular decrease of the water of the Baltic, and the alteration of level of the Mediterranean observed on the coast of Egypt. The most important effect, however, of the contraction of the bulk of the earth, is an acceleration of its rotatory motion. For such is the mechanical relation between the dimensions of the earth and its period of rotation, that if it undergoes contraction of volume, the rotatory motion must be accelerated; whence increase of centrifugal force, causing the level of the ocean to be raised a little between the tropics, and lowered in the polar regions, so that the northern parts of Europe and Asia would be gradually elevated above their former level with respect to the sea.* In this way the numerous islands of the Pacific Ocean may be supposed to be the summits of mountains belonging to a portion of submerged continent. The same relation also affords the means of measuring the secular contraction, for the length of the day is an astronomical element of such importance, that the slightest variation would be immediately detected. But observations sufficiently accurate render it certain, that since the time of Hipparchus, or during the last twenty centuries, the length of the day has not varied by $\frac{1}{200}$ of a second. Hence it necessarily follows, that if the contraction is proceeding, it must be at a rate almost infinitely slow. The amount of contraction, however, cannot safely be taken as a measure of the loss of temperature. The cooling takes place under circumstances very different from those in which bodies are placed when exposed to the free action of the atmosphere, and the ordinary laws of contraction must be greatly modified by the enormous pressure at the depth of twenty leagues beneath the surface.

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* See Book of Science, pt. i. p. 46, &c., for the manner of estimating centrifugal force, and observations on the consequences of its overcoming the force of gravitation.

It has been found that the temperature of springs, as they issue from the earth, varies but inconsiderably at different seasons of the year; and that in our hemisphere they attain their highest degree of heat in general about the month of September, and their lowest towards March, the difference of the two extremes being from 1° to 2° centig. From a table of the mean temperature of springs in different parts of the world compared with that of the air at the surface of the soil, collected from the experiments of different observers, by M. Pouillet, it appears that in the torrid zone, the mean temperature of the air is in general somewhat lower than that of springs; but in the temperate zone the contrary appearances take place, the springs are warmer than the air, their excess of temperature usually increasing with the latitude, so that at 60 or 70 degrees, from the accurate observations of Wahlenberg, it may be concluded that their temperature is from 3° to 4° centig. above that of the air.

Investigations of the heat of Artesian Wells,* have brought to light some important results relative to the internal temperature of the earth. M. Arago collected observations whence it appeared that the greater the depth of such wells, the higher is the temperature of the waters that flow from them. M. Fleuriau de Bellevue found that the temperature of the water at the bottom of an Artesian Well, by the sea side, near Rochelle, 316 feet deep, was 16°.25 centig.; and the boring being afterwards continued to the depth of 369.5 feet, the temperature at the bottom was found to be 18°.12 centig., the mean surface temperature of the country being 11°.87 centig.[*]

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* For an account of the nature of Artesian Wells, see Treatise on Hydrostatics, Book of Science, part i. p. 140.

Though there are various circumstances that might occur to modify the temperature of springs, yet it must be inferred from the preceding observations that some springs display degrees of heat greater than could be supposed to be caused by the influence of the rays of the sun propagated through the superficial strata of the earth. This also still more evidently appears from the temperature of thermal waters, sometimes approaching to the boiling point. The source of heat in springs or fountains of this kind has been the subject of much controversy. Connected as they frequently are with volcanos, their temperature may naturally be imputed to volcanic agency; and when hot springs are found traversing cracks in strata not volcanic, attempts have been made to account for the phenomena by chemical combinations at inconsiderable depths; but the salts usually found dissolved in these waters do not afford support to this theory, and Berzelius has shown it to be untenable with respect to the Carlsbad waters.[†] Numerous instances occur of the existence of thermal springs in tracts of country distant from any open or extinct volcanos. It may, however, be alleged that they may possibly communicate with some deeply-seated foci of volcanic agency; yet admitting such communication, it would only tend to prove that volcanos as well as thermal fountains, owe their origin to central heat.

Among the hot springs obviously connected with volcanos are the Geysers in Iceland, the phenomena of which deserve to be noticed, as the extraordinary effects exhibited serve in some degree to indicate the extent and magnitude of the power by which they are produced.

"These intermittent hot springs rise from a large tract, covered to a considerable depth by a stream of lava, and where thermal water and apertures evolving steam are very common. The Great Geyser rises out of a spacious basin, at the summit of a circular mound, composed of siliceous incrustations, deposited from the spray of its waters. The diameter of the basin or crater, in one direc-

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[*] De la Beche's Geological Manual, 3d ed., 1833, 8vo, p. 12; from Journ. de Geologie, tom. I.

[†] Id. p. 17.

tion is 56 feet, and 46 in another. In the centre is a pipe 78 feet in perpendicular depth, and from 8 to 10 in diameter, but gradually widening as it opens into the basin. The inside of the basin is whitish, consisting of a siliceous incrustation, and perfectly smooth, as are two small channels on the sides of the mound, down which the water makes its escape when filled to the margin. The circular basin is sometimes empty, but is usually filled with beautifully transparent water in a state of ebullition. During the rise of the boiling water up the pipe, especially when the ebullition is most violent, and when the water flows over or is thrown up in jets, subterranean noises are heard, like the distant firing of cannon, and the earth is slightly shaken. The sound then increases, and the motion becomes more violent, until at length a column of water is thrown up perpendicularly with loud explosions, to the height of 100 or 200 feet. After playing for a time like an artificial fountain, and giving off great clouds of vapour, the pipe is evacuated, and a column of steam then rushes up with amazing force and a thundering noise, after which the eruption terminates. If stones are thrown into the crater they are ejected instantly, and such is the explosive force, that very hard rocks are sometimes shivered into small pieces. Henderson found that by throwing a great quantity of large stones into the pipe of Strocke, one of the Geysers, he could bring on an eruption in a few minutes.[*] The fragments of stone, as well as the boiling water, were thrown in that case to a much greater height than usual. After the water had been ejected, a column of steam continued to rush up with a deafening roar for nearly an hour; but the Geyser, as if exhausted by this effort, did not give symptoms of a fresh eruption when its usual interval of rest had elapsed."[†]

Sir George Mackenzie describes the continual discharges of water and steam from the Great Geyser, during its period of excitement, as resembling the distant firing of artillery from a ship at sea; and he estimates the height of the jet as being at least 90 feet. The temperature of the water in the pipe, when sufficiently high for observation, was found to be 209° Fahrenheit.[‡] There are several other alternating hot springs in Iceland, one of which, called the New Geyser, formerly an insignificant fountain, now explodes like that already described; but most of these springs are of inferior magnitude to the Geysers.

The distribution of heat in large masses of water, as lakes and seas, is much more uniform than in the solid strata. This fact, ascertained by Saussure, by means of experiments on the lakes of Switzerland between 1777 and 1784, may be regarded as depending on that property of water, in virtue of which it acquires its greatest density, a few degrees above the freezing point. More extensive observations, however, have shown, that while the temperature of water varies but little at different depths in the temperate zone, it increases with the depth in the polar seas; and this augmentation of temperature in descending, may reasonably be supposed to depend on the influence of central heat.

The temperature of the atmosphere, like that of the sea in the equatorial regions, decreases generally with the distance from the surface. And hence extreme cold prevails at a great elevation. The tops of high mountains in the torrid zone are covered with perpetual snow, and M. Gay Lussac, in his famous aëronautic expedition, having ascended about a league and a half above the city of Paris, experienced a depression of temperature 12° centig. below the freezing point. At greater heights the cold would become utterly insupportable. These circumstances depend chiefly on the absence of reflecting bodies in the higher regions, and the rarity of the air, which affords a free passage to the solar rays, deriving from them but an inconsiderable augmentation of temperature.

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[*] Journal of a Residence in Iceland, p. 74.
[†] Lyell's Principles of Geology, vol. ii. pp. 307—309.
[‡] Mackenzie's Travels in Iceland.

However, though the cold appears to increase with the height throughout the extent of the earth's atmosphere, it is probable that there is a limit in space beyond which the temperature cannot descend. The earth and the other planets may be regarded as moving within a medium of uniform temperature, such as would exist within the sphere of Uranus, if the sun and all the planetary bodies were removed. That such a temperature occurs in the regions beyond the atmosphere, may be inferred from various considerations. The innumerable stars scattered through the heavens, glittering with light as we behold them, cannot be imagined to be destitute of heat, and how feeble soever their influence, in consequence of their distance, they must produce some effect on bodies in surrounding space. Admitting, then, that there is an elastic medium beyond the atmosphere of the earth, as seems to be proved by observations on the periodic revolutions of Encke's comet,* it must have a certain capacity for heat, like all other matter. But whether the temperature of the planetary spaces be caused by radiation from the stars, or be regarded as essentially belonging to the elastic medium, the mathematical investigation of the state of the surface of the earth proves that there must exist a fundamental temperature, independent of the sun or any sources of internal heat; for otherwise, the superficial temperature would be very different, and its decrease from the equator to the poles incomparably greater than it is in reality. If the earth revolved in a medium absolutely destitute of heat, the slightest variations in the sun's distance would occasion sensible changes of temperature, and the diurnal alternations would be fatal to organic life. These effects must be in some degree modified by the presence of the atmosphere, yet the comparatively small variations of temperature which actually take place are incompatible with the existence of a degree of cold in the planetary regions, much beyond the freezing point of mercury. On computing the amount of temperature which the medium without the atmosphere must possess, to account for the existing thermometrical state of the earth's surface, Baron Fourier found that the phenomena are such as would result from the supposition that the celestial spaces have a temperature equal to 50° centig., or 58° Fahrenheit below zero. It should be remarked, that this theory has been to a certain extent confirmed by the researches of M. Svanberg, a Swedish philosopher, who having investigated the temperature of the planetary spaces upon a principle different from that adopted by Fourier, arrived at nearly the same conclusion.[*]

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* The comet distinguished by the name of the German astronomer, Encke, who first ascertained that it had a comparatively short period of revolution, appears to be gradually approaching nearer and nearer to the sun in each successive revolution, whence it follows, that it must move in a resisting medium. Encke stated (in the Berlin Ephemeris, 1823) as the result of his observations, that the periodic time of this comet was shorter than that deduced from earlier investigations. Calculations were subsequently made as to the effect of perturbations of the comet produced by its approach to the planet Jupiter, after making allowance for which, however, it was found that the diminution of its orbit could only be accounted for by the existence of a resisting medium. "The magnitude of the resistance is such, as to diminish the periodic time about 1-10,000th of the whole at each revolution, a quantity so large that there can be no mistake about its existence. The history of this discovery is undoubtedly one of the most curious that modern astronomy has presented."—*Prof. Airy on Astronomy, in Rep. of Brit. Assoc. for* 1832, p. 163. See also Whewell's Astronomy and General Physics, Bridgwater Tr., b. 3, ch. iv.

All the phenomena of temperature, as respects the solid parts of the earth, the waters, and the atmosphere, seem consistent with the hypothesis of central heat; but there is an apparent objection which demands some notice. It might be imagined that the intense heat of the nucleus of the earth is incompatible with the present temperature of its surface. But it has been demonstrated from mathematical investigation of the laws which regulate the propagation of heat, that there *may* exist, not merely at the centre of the earth, but even at comparatively small depths below the surface, a temperature sufficient to fuse the most refractory substances with which we are acquainted.[†]

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[*] Foreign Review, vol. viii. pp. 311, 312; Pouillet Elémens de Phys. Ex. et de Méteorologie, tom. ii. pp. 663—665, 696—700; Berzelius's Annual Report to the Academy of Sciences at Stockholm for 1829; Edinb. Journ. of Science, vol. iii., New Series.

[†] "The following are the most remarkable deductions made by Fourier from

The admission of an original state of igneous fusion of the materials composing the terrestrial globe, their gradual cooling from the surface towards the interior, and the existence during a very protracted period of a central nucleus still intensely heated, may be granted as probable—not only as being supported by the evidence derived from the researches concerning the temperature of mines, springs, and waters in general, in various parts of the world, of which some account has been given—but also because it will account for the structure and figure of the earth, as being a spheroid of revolution, constituting a mass of matter, the density of which increases towards the centre. To the same cause may be attributed the existence of volcanos widely distributed over the globe, and manifesting a common and deeply-seated origin; and the occurrence of thermal springs having their sources far beneath the surface, and sometimes appearing at a distance from the craters of volcanos, though probably in general more or less connected with them in the bowels of the earth. To the evidence for the existence of central heat derived from these considerations, may be added the proofs, that in the temperate and frigid zones of the earth a temperature prevailed, at a very remote period, equal if not superior to the utmost heat of the torrid zone at present; and such as was adapted to call into existence a profusion of organic beings, both in the animal and vegetable kingdoms, on a most gigantic scale.

"As there is great difficulty of conceiving any other than the igneous fluidity of our planet previous to the consolidation of its surface, and as fluidity seems essential to the figure of the earth, it has been sug-

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the analytical investigation of the hypothesis of an internal heat. Supposing the conducting power of the materials of the earth, to equal that of iron, and that the temperature increases by 1-30th of a centesimal degree for every metre of vertical descent (about 1-18th of a degree of Fahrenheit for every yard), which is the rate indicated by observation, the enormous heat accumulated in the interior would cause an augmentation of temperature at the surface, amounting only to a quarter of a degree above that which is due to the heating effects of the sun. This small addition to the effects of solar heat is in proportion to the conducting powers of the envelope, all other circumstances remaining the same; consequently as the conductibility of the superficial materials of the earth is considerably less than that of iron, the augmentation of temperature just mentioned is estimated too high, and probably does not exceed 1-30th of a centesimal degree. Hence the effects of a central heat are altogether insensible at the surface."—*Foreign Review*, u. s. p. 313.

gested that the earliest transition from a liquid to a solid state, consequent on the radiation of heat, would take place at the equator, and that masses of the solidified crust would float upon the incandescent fluid beneath.* The fluid mass would necessarily be influenced by tides: therefore so long as the solidified crust was too thin to resist the effects of this cause, it would be broken up into fragments, the precursors of those of which the solid surface of our globe is every where composed. It may surprise many of our readers, but it is nevertheless true, that when the surface of England is minutely examined, we find there is scarcely any area of eight or ten square miles in extent which has not been fractured or broken up into minor portions, by causes that have acted at various geological epochs. What is thus true of England is found to be also generally true of the whole surface of our continents and islands, when examined with the necessary attention. Sometimes a more modern deposit may mask the surface broken into fragments, the former not having been yet acted on by disrupting forces; but when rocks, on which such deposits rest, are exposed by denudation of any kind, either in ravines, or over a certain extent of horizontal area, they will be found fractured. There must have been inequalities in the earth's surface from its earliest consolidation. The radiation of heat, and the necessity of the exterior solid crust conforming to the fluid surface beneath, could not have done otherwise than produce them. Hence M. Elie de Beaumont's theory of the elevation of mountain chains, which rests on the necessity of the earth's crust continuully diminishing its capacity, notwithstanding the nearly rigorous constancy of its temperature, in order that it should not cease to embrace its internal mass exactly, the temperature of which diminishes sensibly, while the refrigeration of the surface is now nearly insensible."†

INFLUENCE OF EXISTING CAUSES ON THE STRUCTURE AND CONFORMATION OF THE SURFACE OF THE EARTH.

The terrestrial globe, the general dimensions of which have been already stated, is composed of various kinds of matter subsisting in the solid or fluid state, and encompassed by an atmosphere of elastic or gaseous fluids, of uncertain extent, but gradually decreasing in density as it recedes from the earth's surface. The superficial distribution of land and water is extremely irregular, and the area covered by the latter far exceeds the space occupied by the former, which probably does not amount to more than a fourth part of the entire surface. A larger portion of dry land is found in the northern hemisphere than in the southern, that part of the globe which is to the south of the equator, being chiefly covered by the sea, while to the north of the line sea and land are more equally distributed.

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* Croizet et Jobert Recherches sur les Ossemens Fossiles de Dep. du Puy-de-Dôme. 1828.

† De la Beche's Geological Researches, chap. iii. pp. 45, 46.

The surface of the earth exhibits abundance of obvious irregularities, or elevations and depressions, the land rising into mountains in some places, and sinking in others into glens and valleys; and in the parts under the sea similar inequalities of level are found to exist. But though this diversity of configuration appears sufficiently striking when viewed in detail, yet a little consideration will evince that these irregularities are quite unimportant when estimated with reference to the magnitude of the terrestrial spheroid. The loftiest peaks in the world are supposed to be those of Dwalagiri and Chandradabani, in the Himalaya range of mountains north of Hindostan, said to be about five miles above the level of the sea; and on the opposite surface of the globe are the summits of Chimborazo, Illimani, and Sorata, in the ridge of the Andes, the height of which is probably somewhat more than four miles above the sea. The depth of the ocean beneath its common level, it is manifest, can only be calculated conjecturally, beyond those points which can be fathomed with the sounding line; but from calculations founded on astronomical data, Laplace inferred that its mean depth was a small fraction of 25 miles, the difference in the diameters of the earth, owing to the compression or flattening at the poles.* It has been variously estimated at between two and three miles:

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* "On a regardé long-temps la profondeur de la mer comme incalculable, on la disait immense. Il est vrai que par rapport à nous elle est très-grande, qu'elle est incommensurable mécaniquement par nos appareils les plus perfectionnés, et quoique l'étendue des régions marines dont on n'a pu trouver le fond soit très-vaste, on ne doit pas en conclure que ce fond n'existe point. L'astronomie moderne, aidée des grandes lois de la gravitation universelle, nous a dévoilé ce mystère, et M. de Laplace a démontré, par l'influence que la lune et le soleil exercent sur notre planète, que la profondeur moyenne de la

and it may be reasonably concluded that the bottoms of the lowest submarine valleys, or cavities in the bed of the ocean, do not reach further beneath its surface than the summits of the loftiest mountains extend above that level. If, then, five miles be assumed as the height of the most exalted protuberances, and also as the depth of lowest depressions on the solid surface of the earth, the utmost inequalities of level cannot exceed ten miles, which will be little more than $\frac{1}{800}$ part of the diameter of the globe. But the sea covering so large a portion of the exterior of the earth, causes the whole mass to assume the form of a nearly perfect spheroid, irregularly dotted with relatively minute points, the most considerable of which protrudes about $\frac{1}{1600}$ of the earth's diameter above the common level of its surface. Hence our planet viewed from the moon must, like that satellite, exhibit a circular outline. The uneven figure of the earth's surface has been compared to the little risings and indentations on the rind of an orange, but with reference to the diameters of the two bodies, the irregularities of the latter exceed those of the former beyond all proportion; for if the mountains and valleys of the earth were modelled according to the exact ratios of their respective heights and depths, on the surface of an artificial globe one foot in diameter, they would be hardly, if at all, perceptible.

The surface of the earth both above and beneath the level of the sea presents a considerable variety of conformation and arrangement. The higher parts of the land consist of rocks and mountains, disposed in ridges, like the Alps, the Pyrenees, and the Andes, or in detached peaks and headlands, as the Peak of Teneriffe, and the Table Mountain at the Cape of Good Hope. Low lands may form extensive plains, or wide sandy deserts, and marshy tracts, or lines of coast descending to the level of the sea. Ravines, hollows, and valleys, may occur at various heights, rivers sometimes flowing through them to their termination in lakes and seas. As to the form of the solid surface covered with water, some interesting circumstances have been observed. There can be no doubt but the bed of the ocean varies in

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mer ne pouvait dépasser 8000 mètres (environ 4000 toises). Ainsi les plus hautes montagnes s'élèvent au-dessus de la surface des eaux, à la même distance que les abîmes de l'océan s'enfoncent dans l'intérieur de la terre."—*Résumé d'un Cours Elémentaire de Géographie Physique, par J. V. F. Lamouroux, D.E.S., Prof. d'Hist. Nat. à Caen*, 1821, 8vo, p. 166.

level in some measure like the dry land. The numerous islands scattered through the deep are obviously the higher parts of submarine eminences, those portions of which that are under water sometimes forming sloping banks, and sometimes abrupt and perpendicular precipices. The declivities, however, except around coral islands, are not, probably, in general very steep. "The soundings round coasts," says Mr. De la Beche, "present us with no lines which we might consider to be those of valleys, but with extensive areas, which would, if raised above the level of the sea, form great plains, with here and there some minor elevations and deeper depressions, the latter generally in the form of basins. There are indeed some long trough-like cavities in the North Seas, named the Silver Pits, but they present us with nothing like a system of valleys resembling those on dry land. If the British Islands were elevated one hundred fathoms above the level of the ocean, and thus joined to the continent of Europe, they would be surrounded by an extensive area of flat land; for the fall from the [present] coasts to the new sea-coast would be generally so gradual as to present to the eye one great plain."* The area thus described, in which the sea is in general about one hundred fathoms in depth, is bounded on the west and north-west by a line including the British islands, and passing round them from the coast of France to that of Norway; and terminating towards the open sea by a slope, sinking in a comparatively rapid manner into deep water.

It is a curious fact, that there are continental portions of the earth's surface considerably below the common level of the ocean. MM. Parrot and Engelhart appear to have made the discovery, that the Caspian Sea and Lake Aral are beneath the level of the Mediterranean; and M. de Humboldt ascertained that this depression extends to an extensive territory, about 18,000 square leagues in surface. This tract forms an immense basin, the lowest part of which is occupied by the Caspian Sea. The surface of that sea is 334 feet beneath the level of the Mediterranean, 320 feet below the level of the Black Sea, and that of Lake Aral 203 feet; the latter, as appears from the recent measurement of Captains Duhamel and Anjou, being 117 feet above the level of the Caspian.†

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* Geolog. Researches, pp. 189, 190.

† Humboldt Fragmens de Géologie et Climatologie Asiatiques, tom. i. pp. 91, 136.

As there is abundant evidence that those parts of the earth constituting the present continents and islands have been at some period or other covered by water, so it may be concluded that much of the bed of the sea was once dry land; and indeed large tracts have been submerged within the period of historical record. M. De la Beche remarks, that "dry land can only be considered as so much of the rough surface of our globe as may happen, for the time, to be above the level of the waters, beneath which it may again disappear, as it has done at previous different periods."*

General View of the Present State of the Surface of the Earth.

The exterior of the earth not only exhibits numerous variations of level, but it likewise shows a diversity of structure and composition. Independent of the superficial covering formed from the mixture of decayed animal and vegetable bodies with sand, clay, and other materials, arising from the disintegration of stones and rocks, and serving as a nidus for the production and support of a continual succession of plants of every kind, from mosses, fungi, and grasses, to the noblest trees of the forest, there are many peculiar stratified or massive formations,† sometimes extending over vast tracts of country, and sometimes interrupted, mixed, and modified, producing new combinations, and by their various arrangements composing the solid crust of the earth, commonly more or less covered and concealed by vegetable mould and verdure, but occasionally by barren sands or clay, or appearing in the form of rugged, naked, or snow-clad rocks and mountains. These formations, consisting respectively of series of rocks in a certain order of superposition, have been arranged by geologists in groups, distinguished with reference to the supposed time or mode of their production: thus some are designated as primary, secondary, and tertiary; and some as sedimentary or volcanic. From examination of the surface of the earth, it appears that the strata or masses of rocks composing formations and groups have suffered numerous dislocations and interruptions, indicating local and general disturbances, the investigation of the nature and causes of which may advantageously precede more full and particular descriptions of the several groups, formations, and rocks, of which the crust or exterior portion of the terrestrial globe is composed.

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* Geolog. Manual., p. 2.

† "In geognosy the word *formation* either denotes the manner in which a rock has been produced, or *it designates an assemblage of mineral masses so intimately connected, that it is supposed they were formed at the same epoch, and that they present in the most distant parts of the earth the same general relations, both of composition and of situation with respect to each other.* Thus the formation of obsidian and basalt is attributed to subterranean fires; and it is also said that the formation of transition clay-slate contains Lydian stone, chiastolite, ampelite, and alternating beds of black limestone and of porphyry. The first acceptation of the word is the most conformable to the genius of the French language; but it relates to the origin of things, and to an uncertain science founded on geogonic hypotheses. The second acceptation, now generally received by the French mineralogists, has been borrowed from the celebrated school of Werner, and indicates, not what is supposed to have been, but what now exists. In the geognostic description of the globe, we may distinguish different modes of grouping mineral substances as we ascend to more general ideas. Rocks which alternate with each other, which are found usually together, and which display the same relations of position,

Whatever may have been the cause of the original formation of the oldest rocks, whether with the Wernerians we ascribe them to aqueous solution and crystallization, or with the Huttonians to igneous fusion, their production necessarily infers a concurrence of circumstances no longer existing. The case is different with respect to the superior strata composed of the ruins of the older rocks, and which, from their containing imbedded both animal and vegetable remains, must obviously have been formed at periods subsequent to the origin of organized beings. Therefore as the structure and arrangement of such rocks may be supposed to have been influenced by causes having some analogy with the existing order of things, an inquiry into the nature and extent of the changes now going on upon the earth's surface may be expected to throw some light on the geognostic history of those formations which took place long before the human species was called into existence.

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constitute the same *formation:* the union of several formations constitutes a geological series or group (*terrain*); but the terms, rocks, formations, and *terrains*, are used as synonymous in many works on geognosy."—*Humboldt's Geognostical Essay on the Superposition of Rocks*, translated from the French 1823. p. 1.

Influence of Air, Water, and Volcanic Fire, on the Surface of the Earth.

Many of the changes that are effected on the superficial portion of the globe, are either directly or indirectly owing to the operations of man: the cutting down of woods and forests, draining lakes and marshes, recovering tracts of lands by embankment from the sea, leveling, mining, digging canals, constructing roads and causeways, with various other works that result from human skill and industry, contribute more or less to produce alterations on the face of the earth; but their agency is either remote and contingent, or comparatively insignificant, and therefore need not be particularly investigated. It is of more importance to consider the influence of the elements displayed on a far more extensive scale with regard either to time or space, and producing correspondent effects. Air, water, heat, and perhaps electricity, sometimes acting slowly and gradually through long periods, may modify or change the form and constitution of substances composing the solid crust of the earth; and on other occasions display overpowering force and violence, giving rise to storms and hurricanes, tides, currents, torrents and deluges, earthquakes and volcanos, spreading desolation and ruin over wide tracts of land, breaking up and displacing existing strata, or covering them with beds of new matter, replacing valleys by mountains, or mountains by valleys, and thus producing strange metamorphoses in the appearance of those countries over which their influence extends. These powers of nature, however, are not solely active in works of destruction, their agency sometimes being productive of new formations. Air and heat may occasionally operate in this way, but the formative effects of water are more obvious and extensive. Rivers deposit sands, detrital matter and silt, filling up lakes, and constituting deltas on the margin of the sea, or shoals, sandbanks, and islands, rising amidst its waves; lapidescent springs yield deposits of siliceous earth, tufa, travertin, and stalactitic limestone; and the water of the sea in some manner facilitates the operations of the little animals employed in building coral reefs and islands.

The influence of the atmosphere in modifying the surface of the earth, whether destructive or formative, may depend either on the chemical or the mechanical properties of the aërial fluids of which it is composed. Air must be a powerful chemical agent, in consequence of its containing oxygen and carbonic acid. The action of oxygen may cause the disintegration of rocks in which metals and metallic sulphurets are included; and, by its universal affinity for other bodies, it may give rise to numerous decompositions and combinations, the modifying effects of which must be alike extensive and important.

Carbonic acid, which is constantly present in the atmosphere in a relatively small proportion, occurs abundantly in certain situations, being given off from the surface of springs, or issuing from fissures in the earth. It is chiefly evolved in coal-pits and in volcanic districts. Among the most noted natural laboratories of carbonic acid is the Grotto del Cane, near Naples, the phenomena of which have often been described; and many others occur in different parts of the world. This gas is disengaged in vast quantities from every part of the Limagne d'Auvergne, in France, where it appears to have been produced in equal abundance from time immemorial. This elastic fluid being invisible, it is only observed in consequence of its effects, as when an excavation is made, in which it accumulates, and a lighted candle or other burning body introduced into it becomes extinguished. There are some springs in this district, where the water is seen bubbling and boiling from the copious disengagement of this gas. It has an obvious effect on the vegetation, many trees, as the walnut, flourishing more luxuriantly than they would otherwise do in the same soil and climate, probably owing to the rapid absorption or decomposition of carbonic acid. This gas is found in springs issuing from granite near Clermont, as well as from the tertiary limestones of the Limagne.[*] In the environs of Pont-Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which there are lead-mines, has been found quite saturated with carbonic acid, which is continually given off in the gaseous form. The carbonates of iron, lime, and manganese, are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked.[†] Dolomieu notices the frequent evolution of carbonic acid in the vicinity of Mount Etna, and especially near Paterno. "An immense quantity is disengaged from the surface of a cold spring called *Acqua Rossa*, to the water of which it communicates a powerfully acid taste, and gives it the appearance of ebullition. This gas seems to be pure carbonic acid, proving suddenly fatal to animals that respire it, many being tempted by the freshness and limpidity of the water, shaded by bushes and reeds, to quench their thirst. Hares and birds are often found dead on the banks of this spring."[*] Similar effects are stated by MM. Bischof and Noggerath to be produced by the exhalation of carbonic acid from the vicinity of the lake of Laach, the quantity of which has been estimated at 600,000 pounds a day. In the Brohlthal, on the Rhine, an old volcanic country, there is a considerable evolution of carbonic acid gas, which is employed by M. Bischof in the manufacture of chemical preparations on a large scale.[†] Near Fort Diadine, on the Euphrates, in Armenia, are mineral springs, impregnated with carbonic acid and sulphuretted hydrogen, two of which are remarkable for the deposition of large quantities of carbonate of lime. In the environs of these two springs the limestone contains much native sulphur, which for a long time was collected; but, the carbonic acid arising having suffocated many of the workmen, the undertaking was abandoned. The acid gas issues in this place from the bowels of the earth in such great quantities as to fill the caverns and neglected excavations, forming numerous strata of livid vapours. It is sometimes evolved with so much rapidity through the clefts as to produce a strong current and a hissing noise. Small birds seeking refuge in these caverns, or coming near the fissures, are suddenly stifled.[‡]

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[*] Le Coq Annales de l'Auvergne, tom. i. p. 217. May, 1828.

[†] Lyell's Prin. of Geol., vol. i. p. 317, from Ann. d'Auvergne, June, 182
See also G. Poulett Scrope's Memoir on the Geology of Central France.

But perhaps the most extraordinary phenomenon of this kind in the world is the Guevo Upas, or Valley of Poison, in the Island of Java; the deadly effects of which contributed in no small degree to give currency to the fabulous reports of the existence of a wonderful tree called the Bohun Upas, so fancifully described by Dr. Darwin, in his "Botanic Garden." The district in which this valley is situated was visited by Mr. A. Loudon, who states that it is three miles from

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[*] Mémoire sur les Isles Ponces; et Catalogue Raisonnée de Produits de l'Etna. Paris, 1788. p. 364.

[†] De la Beche's Geol. Man., pp. 154, 155.

[‡] Boué Mémoires Géologiques et Paleontologiques. 1832. tom. i. p. 221.

Balor, on the road to the Djung. He describes it as about half a mile in circumference, of an oval form, from 30 to 35 feet in depth, and quite flat at the bottom; destitute of vegetation, being covered with skeletons of human beings, tigers, hogs, deer, peacocks, and various sorts of birds, which have perished by entering into the atmosphere of carbonic acid, with which the lower part of the valley is filled. There were no visible openings in the ground at the bottom, which appeared to be of a hard sandy substance. The sides of the valley are covered with trees and shrubs; and it may be concluded that the gas does not rise above 18 feet from the bottom, as Mr. L. and others with him descended to that depth, where they experienced no difficulty of breathing or inconvenience, except that which arose from the offensive odour of the putrefying bodies below.* No smell of sulphur, or traces of volcanic matter were observed; but there can be no doubt but the production of carbonic acid in this situation is connected with volcanic influence, which extends throughout Java, and many of the neighbouring islands.

The effect of carbonic acid, as a chemical agent, both as commonly present in atmospheric air, and as more abundantly occurring in such localities as those above described, must depend on the nature of the rocks and other bodies with which it may come into contact. It may thus cause the decomposition of granite, gneiss, and other feldspathic and micaceous substances, by combining with the potash, soda, or lithia, which enter into their constitution. On the contrary, when it encounters lime or magnesia, it may contribute to the production of new rocks. "The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Clermont. This decay was called by Dolomieu, 'la maladie du granite;' and the rock may with propriety be said to have *the rot*, for it crumbles to pieces in the hand. The phenomenon may without doubt be ascribed to the continual disengagement of carbonic acid gas from numerous fissures."†

The chemical action of carbonic acid, as it exists in the usual state of the atmosphere near the earth's surface, though much more gradual, and therefore less noticed than where it is copiously evolved from the water or soil, as in volcanic countries, is yet sufficiently powerful to produce a manifest effect on the structure of large masses of granite and rocks of analogous composition. In the western parts of this island, where primitive formations prevail, granite masses not unfrequently occur, which from their peculiar forms received the Celto-cymric appellations of Logan, Tolmen, and Kistvaens; and were by Dr. Borlase and other antiquaries long regarded as works of art of Druidical origin; but these rocking-stones, rock-basins, cheese-rings, and altars, are now generally admitted to be blocks of granite, which have acquired their respective forms in consequence of superficial decomposition or disintegration. The manner in which this takes place may be illustrated by the following figure of a group of such decaying rocks, forming a part of Great Staple Tor, on Dartmoor, in Devonshire, seen from the south-west.[*]

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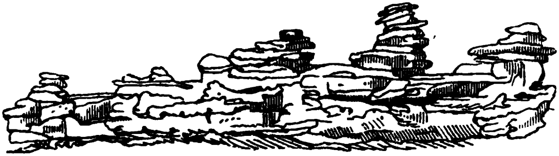
* Journal of Geographical Society, vol. ii.

† Lyell's Prin. of Geol., vol. i. p. 317.



Mr. De la Beche remarks, that it is "more like the remains of some huge building or battlement, than the effect of cleavage and decomposition, which it is." Granite is not generally regarded as a stratified rock, like gneiss and mica slate; but it is a fact well known to the workmen who are employed in quarrying and cutting it, that it has what they term a *grain*, or that it will split in one or two directions more easily than in others.[†] This doubtless is owing to the arrangement of the mineral bodies of which it is composed, and especially the feldspar, the decomposition of which must essentially aid the process of disintegration, and determine in a great degree the direction in which it takes place.

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[*] From De la Beche's Geological Researches.

[†] Dr. Boase, who, from analogy of structure between granitic and schistose rocks infers their common origin, has adduced sufficient evidence of an approach to stratification in the former. See his Treatise on Primary Geology. 1834. ch. vi.

There are other gases which are copiously evolved in some situations, and particularly in the vicinity of volcanos. Dolomieu states, that he ascertained the presence of sulphurous acid, muriatic acid, hepatic gas or sulphuretted hydrogen, phlogisticated or nitrogen gas, and inflammable air or hydrogen, as well as carbonic acid, in the exhalations from the surface around Mount Etna;* and other observers have noticed the occurrence of chlorine gas. But the most abundant of the spontaneously produced gases, next to carbonic acid, probably is carburetted hydrogen, well known as an agent of destruction in coal-mines. It is likewise sometimes emitted from the surface of the soil, or of springs and wells. The country around Baku, on the western shore of the Caspian Sea, is remarkable for its numerous mud volcanos and fountains of naphtha, the soil apparently being every where impregnated with bituminous matter. About ten miles to the north-east of Baku there are many old temples of the Guebres or fire-worshippers, in each of which there is a jet of inflammable gas issuing from apertures in the earth. Within an area of two miles in circumference, if holes be made in the earth, gas immediately rises, and may be set on fire by a lighted torch. The inhabitants fix hollow canes in such holes, and light the stream of gas from the top, availing themselves of the light and heat for domestic purposes. The flame is easily extinguished by plugging up the orifice of the tube. Besides the sacred and domestic fires, there is a large one which springs from a natural cliff in an open situation, and which burns continually. Mr. Kinneir states, that the whole country round Baku has at times the appearance of being enveloped in flames. "It often seems," he says, "as if the fire rolled down from the mountains in large masses, and with incredible velocity; and during the clear moonshine nights of November and December, a bright blue light is observed at times to cover the whole western range. This fire does not consume, and if a person finds himself in the middle of it no warmth is felt." †

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* Mémoire sur les Isles Ponces, &c., pp. 360—363.

† See Hanway's Travels in Persia, vol. i.; Geo. Forster's Travels overland to India; Macdonald Kinneir's Geographical Memoir on Persia; Engelhardt and Parrot's Travels in the Crimea and Caucasus in 1815, vol. i.; and Humboldt Fragmens Asiatiques.

Captain Beaufort describes an ignited jet of inflammable gas, called the Yanar, near Delictash, on the coast of Karamania, anciently perhaps the object of religious veneration. He states, that "in the inner corner of a ruined building, the wall is so undermined as to leave an aperture of about three feet in diameter, and shaped like the mouth of an oven: from this the flame issues, giving out an intense heat, yet producing no smoke on the wall." Though the wall was scarcely discoloured, a little caked soot appeared in the neck of the aperture. The hill is composed of crumbly serpentine and loose blocks of limestone. At a short distance down the hill there is another aperture, which from its appearance may have given out gas. The Yanar is supposed to be of ancient date, Pliny having described a similar phenomenon, probably with reference to this spot.* Such jets of inflammable gas have been observed in a mountain in the island of Samos, in a temple at Chittagong in Bengal, and near salt springs in China. Both in Europe and America the spontaneous production of carburetted hydrogen has been taken advantage of for economical purposes. In the salt-mine of Gottesgabe, at Reine, in the county of Tecklenberg, there is an opening called the Pit of the Wind, from which a continuous current of this gas has issued for sixty years. M. Roeders, inspector of the mines, has, for a few years past, employed this natural gaslight for the purposes of illumination and for cookery.† Near the village of Fredonia, New York, N. A., are a number of what are called burning springs; and gas issues from them, which is collected in a gasometer, and conveyed by pipes to the village, which is thus lighted. The same kind of gas is evolved more copiously in the bed of a stream about a mile from the village. It consists of carburetted hydrogen, supposed to be derived from beds of bituminous coal.‡ A current of gas resembling this last was discovered in 1828, in the bed of a rivulet which crosses the north road between Edinburgh and Glasgow, about seven miles from the latter city. It is said to be emitted for more than half a mile along the banks of the rivulet; and in one place, where many jets issued within a yard square, it was set on fire, and burnt uninterruptedly during five weeks, giving the clay soil the appearance of powdered brick.§

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* Karamania; or, Brief Description of the Coast of Asia Minor. 1817.

† Edinb. Journal of Science, No. xv. p. 183. ‡ Idem.

§ Edinb. Journal of Science, No. i., N. S., pp. 71—75.

The extrication of inflammable gases from the bowels of the earth is interesting, as tending to illustrate the peculiar geological structure of various distant portions of the earth's surface; and the gases issuing from volcanic districts must have some influence on the nature of the minerals occurring in such situations, but the quantities in which they are thus produced are relatively insignificant, and their formative or destructive effects must take place to an extent far inferior to those occasioned by oxygen and carbonic acid.

Gases are not the only kinds of foreign matter contained in the atmosphere, which forms a receptacle for all such bodies, whether fluid or solid, as are at any time exposed to its action, and are rendered capable of elevation by their inferiority of specific gravity. Water, however, appears to be the only kind of matter which occurs in sufficient quantities in the atmosphere, to produce any considerable effect on the surface of the earth in consequence of its chemical properties. From its solvent power it must materially aid the operation of carbonic acid in the decomposition of rocks, and that property alone, as it is widely dispersed, and in some places in great abundance in the lower strata of the air, renders it a formidable agent of destruction. It has sometimes been supposed that the atmosphere abstracts water from the sea, holding in solution muriatic acid or salts. But from the experiments of M. Roubaudi at Nice, on the coast of the Mediterranean, it appears that when the sea is calm, the air on the sea-shore and over the sea contains neither muriatic acid nor muriates, though when the sea is rough, and particularly if the wind is high, particles of sea-water, in a state of great tenuity, float in the air, but the distance to which they may be carried inland, will necessarily depend on the force and direction of the wind.*

The action of the atmosphere on the superficial strata of the earth varies according to the circumstances under which it takes place. When it is in a state of repose its effects must principally depend on its properties as a chemical agent; and these have been already noticed. Air when in a state of agitation, as during the prevalence of winds, storms, tempests, hurricanes, and tornados, becomes a mechanical agent of vast power: but its influence is so generally blended with that of aqueous showers and currents, that it is difficult to ascer-

* Journal de Pharmacie, 1833.

tain the exact extent to which it operates, and as the subject of aërial oscillations and disturbances belongs to meteorology, a few observations only will be requisite here relative to the effect of commotions in the atmosphere on the surface of the earth.

Even when the air is perfectly still, the power of gravitation necessarily causes the ascent of all loose bodies from the earth, which are inferior in specific gravity to the lower aërial strata, and extremely minute particles of heavier matters are also elevated, probably from the action of temperature, producing very inconsiderable currents. It is in consequence of their wonderful tenuity, that the seeds of cryptogamous plants, as mosses, fungi, and lichens, are often transported to great distances through the air, and thus such plants are found vegetating in situations in which it would be impossible otherwise to account for their existence. "The sporules of fungi," observes Fries, "are so infinite, that in a single individual of *Reticularia maxima,* I have counted above ten millions, and so subtile as to be scarcely visible, often resembling thin smoke, so light that they may be raised, perhaps, by evaporation into the atmosphere, and dispersed in so many ways by the attraction of the sun, by insects, wind, elasticity, adhesion, &c., that it is difficult to conceive a place from which they may be excluded."*

To what great distances heavy substances in a state of minute division may be conveyed through the air, will appear from the following observations, made at Barbados, during a volcanic eruption in the island of St. Vincent's, which is about seventy miles directly westward from it: "In the night preceding the 1st of May, 1812, the inhabitants and the garrison of Barbados were alarmed by the noise of explosions from the westward, which seemed to proceed from fleets engaged at sea in that direction. At two or three in the morning there was a strange sort of dust dropping from the air, which increased as the morning advanced. When daylight appeared, a large body of vapour appeared to the northward of the east, slowly advancing over the island, producing in a manner sufficiently obvious, a darkness in the quarter from which it came, carrying before it a bright portion of the sky, bounded by an apparently circular line of dimensions successively diminishing until entirely shut in, and complete darkness covered all things. The ordinary darkness of night, always illuminated more or less by starlight, was not to be compared to this. It was total and absolute. The eye could not see the hand. It was an Egyptian darkness that might be felt. The dust continued to increase, and fell in such large quantities, as to cover every thing to the depth of more than an inch, and even to break down the branches of trees by lying on them. Between twelve and one o'clock in the day, a vertical shadowy light began to appear, the passage of light from the atmosphere above being shortest in that direction through the dust, in a circular form, which as the dust thinned away, or drove on, increased in diameter, until the whole body of particles passed away visibly. By the impalpable particles of dust thus deposited, for many days men and animals were grievously annoyed, even the tender leaves of plants were injured, and the wind agitating the dust, the whole face of the country showed like the crater of a volcano. The volcano of St. Vincent's had burst out. The dust, thrown by the explosions to considerable heights, had, by the higher currents of air, been carried to windward during the night, and, descending into the lower regions of the atmosphere, was driven back over the island by the ordinary trade-wind a little to the north of east. During the fall, patterings on the roofs of houses, as of grosser particles than dust, were repeatedly heard, and some of the dust sent to me contained particles of stones, whose dimensions seemed to exceed all the power of floatage, so gross that I was led to conceive that they were carelessly taken up from the soil on which the dust lay. Other portions of dust were free from these. An analysis of this dust, in the laboratory of the Royal Institution, by Mr. Faraday, gives the following components: silex 78, alumine 11.2, lime 7, oxide of iron 3.4, loss .4 = 100.*

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* Lindley's Introduction to the Natural System of Botany.

"This floatage power of small bodies may account for the dust said to be observed on the tops of the highest mountains, to which the finest particles of smoke, and of whatever solid materials may be adequately divided, so as to be elevated and dispersed in air, may rise, and in a given state of rest in the air above, unknown below, may quietly be deposited, and undisturbedly repose."†

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* The small amount of loss, about 1-200th of the whole, may probably have been owing to the escape of hygrometric moisture.

† *On the Floatage of Small Heavy Bodies in Air*, by G. W. Jordan, F.R.S. Journ. of Science, vol. viii. pp. 251—253.

During an eruption from the volcanic mountain of Tomboro, in the island of Sumbawa, in 1815, which will be subsequently noticed, the fall of dust and ashes was so great at Bima, forty miles eastward of the volcano, as to break down the roofs of the residency and other houses; and on the side of Java, the volcanic powder was carried 300 miles, and more than 200 towards Celebes, in sufficient quantity to darken the air.

The influence of the atmosphere in modifying the surface of the earth must obviously be greatly augmented during the prevalence of high winds. Thus are formed *dunes* and sand-hills, which sometimes overwhelm cultivated fields, and the habitations of man, transforming fertile plains into barren trackless wastes. Such phenomena have taken place in the south of France, in Egypt, and in different parts of Scotland.

Cuvier remarks, that where the sand thrown up by the sea is left loose, it advances as irresistibly over the land as the silt and other alluvial matter carried down by rivers does over the bed of the sea. In their progress the sands push before them large pools formed by rain, intercepting their communication with the sea. On the coast of the Bay of Biscay they have overwhelmed many villages mentioned in records of the middle ages; and in the department of the Landes alone, ten are now threatened with destruction. Mimisan, one of these villages, has for twenty years been struggling against them, while a sand-hill more than sixty feet in height is approaching it. Their progress has been estimated at sixty feet annually, and in some places at seventy-two feet. According to this calculation they might in two thousand years reach Bourdeaux; and, from their present extent, it must have been about four thousand years since they began to be formed.*

The sands of the Libyan desert, driven by the west winds, have covered all the land formerly capable of tillage on the western bank of the Nile. Denon, in his "Travels in Lower and Upper Egypt," says that the summits of the ruins of ancient cities buried under these sands still appear externally.

In Morayshire, N. B., westward from the mouth of the river Findhorn, a district consisting of more than ten square miles of land, once termed, from its fertility, the Granary of Moray, has been depopulated and ruined by a sand-flood. The eruption commenced about 1677, and its progress was gradual; but in 1697 not a vestige was to be seen of the manor-house, orchards, and offices of Coubine, two-thirds of the barony so called having been then destroyed, and the sand was daily gaining ground. This sand came from Maviestou, on the coast, seven miles west from the mouth of the Findhorn, where from time immemorial there have been large accumulations of sand. It appears, however, that the catastrophe of Coubine "was occasioned by the bad practice of pulling bent and juniper," which occasioned an act of the Scottish Parliament, dated July 16, 1695, for the preservation of lands adjacent to sand-hills. The cause thus assigned as the origin of the devastation of Coubine, suggests an obvious remedy, in the plantation of vegetables which will grow in a sandy soil, such as the *Arundo arenaria*, and the *Elymus arenarius*, the spreading fibrous roots of which give stability to the loose surface.*

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* Cuvier's Theory of the Earth, pp. 133—135.

Sands and fragments of sea-shells are sometimes raised from the beach to very considerable heights by violent winds, as is the case with the sands of Barry, at the north side of the estuary of the Tay, where hills have been formed by them 140 feet high.†

Hurricanes, from their extraordinary force and violence productive of effects far beyond those of high winds, are generally accompanied by storms of rain, and the result of their influence, therefore, is partly owing to the impulse of gusts of air, and partly to that of floods of water. "They are of geological importance," says Mr. De la Beche "as by the sudden application, if I may so express myself, of a furious wind and deluges of rain to the surface of land, very considerable changes are in a short time produced on that surface."‡ The velocity of the wind in hurricanes has been estimated at from eighty to one hundred miles an hour. The hurricanes that occasionally ravage the Antilles, the Isles of France and Bourbon, Siam, China, Japan, and other countries between and near the tropics, overthrow solid edifices, uproot the strongest trees, involve animals and the produce of the fields in one common ruin, and sweep to a distance vast masses of solid matter. The desolating power of hurricanes may be estimated from the ensuing account of one which visited Guadeloupe, July 25, 1825. Houses firmly built were overturned; and a new structure erected at the expense of government, in a most substantial manner, was ruined. The force and rapidity of the wind was such as to drive tiles through the thick doors of warehouses. A deal plank, about 39 inches long, 9$\frac{4}{5}$ inches wide, and $\frac{8}{10}$ of an inch thick, was carried with such extraordinary velocity through the air, that it passed directly through the trunk of a palm-tree 17$\frac{7}{10}$ inches in diameter. A piece of wood 7$\frac{4}{5}$ inches square, and from 4 to 5 yards in length, was driven by the wind through the surface of a hard, beaten, and frequented road, to the depth of about a yard. A fine iron-railing before the government house was entirely broken. Three pieces of cannon, twenty-four pounders, were dismounted, and driven against the breastwork of the battery in which they were placed. The accuracy of this statement was verified by inquisition on the spot, by General Baudrand, of the French engineers.*

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* See Illustrations of Cuvier's Theory of the Earth, by Prof. Jameson, Note G.

† Lyell's Princip. of Geol., vol. i. p. 343.

Geolog. Man., p. 149.

The effect of air in modifying the surface of the earth, where it acts independently, is chiefly the result of its chemical properties: water is perhaps most efficient as a mechanical agent. The influence of water, like that of air, is apparent both as a destructive and as a formative or constructive power; dissolving or wearing away solid surfaces in one situation, and depositing beds of transported matter in another. Indeed these operations must almost always be simultaneous or successive, the detritus of rocks and of organic bodies, removed by the agency of water from the higher parts of a country, serving to form new tracts of land, by filling up lakes, or composing deltas, sandbanks, or islands encroaching on the sea.

Mr. De la Beche, after describing the manner in which the disintegration of rocks may take place, owing to the protracted action of atmospheric moisture, and the more rapid and violent operation of streams and torrents in the degradation of land, says, "This destruction of the surface is common to most countries; and if a rock so weathered be limestone, there is not unfrequently a reconsolidation of the parts by means of calcareous matter deposited by the water that percolates through the fragments, and which dissolves a portion of them. At Nice, the fractured surface thus reunited is so hard, that if it occur on a line of road it must be blasted by gunpowder for removal. There are some fine examples of this reconsolidation upon the limestone hills of Jamaica; as for example, near Rock Fort, and at the cliffs to the eastward of the Milk River's mouth.

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* Pouillet Elém. de Phys. Exper. et de Meteorol., tom. ii. pp. 717, 718.

"The feldspar contained in granite is often easily decomposed, and when this is effected, the surface frequently presents a quartzose gravel. D'Aubuisson mentions, that in a hollow way, which had been only six years blasted through granite, the rock was entirely decomposed to the depth of three inches. He also states, that the granite country of Auvergne, the Vivarais, and the eastern Pyrenees, is frequently so much decomposed, that the traveller may imagine himself on large tracts of gravel.*

"Some trap-rocks, from the presence of the same mineral, are so liable to decomposition, that there is frequently much difficulty in obtaining a specimen. The depth to which some rocks of this nature are disintegrated in Jamaica is often very considerable."†

The powerful effect of the continued action of running water on compact rock appears from the manner in which the river Simeto, in Sicily, has cut through a bed of lava. At the western base of Etna a great current of lava descending from near the summit of the principal volcano, flowed over the alluvial plains of Simeto, the largest of the Sicilian rivers, which skirts the base of the mountain, and falls into the sea a few miles south of Catania. The lava entered the river about three miles above the town of Aderno, and not only filled its channel for some distance, but flowing to the opposite side of the valley, accumulated there in a rocky mass. The eruption is supposed to have taken place in 1603, and the appearance of the current proves that it is of modern date, for it has not been crossed or covered by any other stream of volcanic matter. In the course, therefore, of about two centuries, the Simeto has eroded a passage from fifty to several hundred feet wide, and in some parts from forty to fifty feet deep. The mass of lava cut through is not porous or scoriaceous, but a compact, homogeneous, hard blue rock; and the general declivity of the bed of the river in this place is not very considerable.*

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* Traité de Géognosie; ou, Exposé des Connaissances actuelles sur la Constitution Physique et Minérale du Globe Terrestre, tom. i.

† Geolog. Man. p. 45.

A more striking example of the detrition of solid rocks by flowing water is exhibited at the falls of Niagara, in North America. At these falls "the water is divided by a small island, which separates the river into two cataracts, one of which is six hundred yards, and the other three hundred and fifty yards wide: the height of the fall is from one hundred and forty to one hundred and sixty feet deep. It is estimated that 670,000 tons of water are dashed every minute with inconceivable force against the bottom, and wearing down the adjacent rocks. Since the banks of the cataract were inhabited by Europeans, they have observed that it is progressively shortening the distance of the falls from Lake Erie. When it has worn down the intervening calcareous rocks, the upper lake will become dry land, and form an extensive plain or valley, surrounded by rising ground, and watered by a river or smaller lake, which will occupy the lowest part. In this plain future geologists may trace successive strata of fresh-water formation, covering the subjacent ancient limestone. The gradual deposition of minute earthy particles, or the more rapid subsidence of mud from sudden inundations, will form distinct beds, in which will be found the remains of fresh-water fish, vegetables, and quadrupeds."

"Mr. Joseph Henry, in a topographical sketch of the state of New York, says, 'The descent of the country from Lake Erie to Ontario, is principally by a step, not at the falls, but at Lewis Town, several miles below. In viewing the position of the falls, and the features of the country round, it is impossible not to be impressed with the idea, that this great natural *race-way* has been formed by the continued action of the irresistible current of the Niagara, and *that the falls*, beginning at Lewis Town, *have, in the course of ages, worn back the rocky strata to their present site.* The deep chasm through which the Niagara passes, below the falls, is nearly a mile wide, with almost perfect mural sides.'—*Transactions of the Albany Institute.*"†

The bed of the river below the falls is strewed with huge fragments of rocks, hurled down by the cataract. The retrogression of the waterfall, owing to the destruction of the surface over which it takes its course, is said to have amounted to nearly fifty yards during the last forty years. If the excavation always proceeded at the same rate, it must have required about ten thousand years for the formation of the whole ravine; and it would take up more than thirty thousand years from the present time before the channel would be worn backward to Lake Erie, a distance of twenty-five miles.

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* Lyell's Prin. of Geolog., vol. i. pp. 258—260.

† Bakewell's Introduction to Geology, 4th ed., 1833, pp. 315—317.

The power of running water in removing stones and heavy materials, and changing the face of a country, was remarkably exemplified in the effects of the great flood which happened in August, 1829, in the province of Moray, and adjoining districts, in Scotland. The storm which occurred on this occasion displayed all the characteristic violence of a tropical hurricane. The inundating rivers were the Nairne, the Findhorn, and the Spey, with their numerous tributaries. All the low intervening lands were covered, and the bridges and buildings along the banks were in general swept away. The plain of Torres was inundated to an extent of twenty square miles, and the destruction every where great. On the Nairne a fragment of sandstone rock, fourteen feet long, three feet wide, and one thick, was carried more than two hundred yards down the river. Some new ravines were scooped out on the sides of the mountains, where no streams had previously flowed, and ancient river-channels, which had never been filled from time immemorial, gave passage to copious floods.

Sir Thomas Dick Lauder, of Fountain-hall, who published a narrative of this occurrence, has given the following animated description of the devastation which took place in his own ornamented domain. "We were roused while at dinner by the account the servants gave us of the swollen state of the rivers; and in defiance of the weather, the whole party sallied forth. We took our way through the garden towards the favourite Mill Island. The magnificent trees on the island were overthrown faster and faster, offering no more resistance to their triumphant enemy than reeds before the mower's scythe. Each one as it fell gave one enormous splash on the surface, then a plunge; the root appeared above water for a moment; and then uprose the stem, disbranched and peeled; after which, they either rolled round in the caldron, or darted like arrows down the stream. Besides the loss of the Mill Island, which I had looked for, the beautiful hanging bank, covered with majestic forest and ornamental trees of all kinds, and of growth so fresh and vigorous, had vanished like the scenery of a dream; and in its place was the garden hedge, running for between two and three hundred yards along the brink of a red alluvial perpendicular precipice, fifty feet high, with the broad, remorseless flood rolling at its base, eating into its foundation, and every successive minute bringing down masses of many cubic yards. And then, from time to time, some tall and graceful tree, on the brink of the fractured portions of the bank at either end, would slowly and magnificently bend its head, and launch into the foaming waves below. The whole scene had an air of unreality about it that bewildered the senses. It was like some of those wild melodramatic exhibitions, where nature's operations are out-heroded by the mechanist of a theatre, and where mountains are thrown down by artificial storms."*

A bridge of granite over the Dee, at Ballatu, consisting of five arches, with a water-way of 260 feet, which had stood firm for twenty years, was destroyed and swept away by the torrent, the whole mass of the masonry having disappeared in the bed of the river. "The river Don," says Mr. Farquharson, in his account of this catastrophe, "has, upon my own premises, forced a mass of four or five hundred tons of stones, many of them two or three hundred pounds weight, up an inclined plane, rising six feet in eight or ten yards, and left them in a rectangular heap, about three feet deep, on a flat ground; the heap ends abruptly at its lower extremity."†

Animals, as well as trees and the produce of the fields, were involved in the general ruin caused by the flood, the effects of which at the mouth of the river Spey are thus described: "For several miles along the beach, crowds were employed in endeavouring to save the wood and other wreck with which the heavy rolling tide was loaded; whilst the margin of the sea was strewed with the carcasses of domestic animals, and with *millions* of dead hares and rabbits. Thousands of living frogs also, swept from the fields, no one can say how far off, were observed leaping among the wreck."‡

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* An Account of the Great Floods of August, 1829, in the Province of Moray, by Sir T. D. Lauder, Bart., 1830.

† Account of the Flood, by the Rev. James Farquharson, in Quarterly Journal of Science, New Series, No. xii. p. 331.

‡ Sir T. D. Lauder's Account, p. 312.

It has been remarked, that the transporting effect of water is vastly augmented by the relative diminution of specific gravity in bodies more or less immersed in that fluid;* and when ice adheres to detached rocks, the joint masses become really lighter than the stony substances would be separately. Hence we may in some measure account for the distribution of large blocks of granite over the surface of several parts of Europe, at great distances from the primitive rocks whence they appear to have been derived.

The phenomena caused by floods, debacles, and torrents, manifesting the sudden effect of powerful impetus, imposing as they are, cannot have contributed so extensively to the production of the changes apparent on the surface of the earth, as the slow but indefinitely protracted operation of running water more or less loaded with silt and sand, and conveying it from higher to lower levels, to extend the limits of old continents, or form the foundations of new ones. Professor Robison, in an article on "Rivers," in the Encyclopædia Britannica, has furnished some estimates of the effects of flowing water, whence it appears that a velocity of three inches per second at the bottom will just begin to act upon fine clay in a firm state, and tear it up; a velocity of six inches will lift fine sand, that of eight inches will raise sand as coarse as linseed, twelve inches will sweep away fine gravel, twenty-four inches will roll along rounded pebbles an inch in diameter; and it requires a velocity of three feet per second to sweep along shivery angular stones of the size of an egg.

Whatever matters may be taken up by flowing water will be again deposited as soon as the velocity of the stream becomes inferior to that which caused their removal; so that only the finer particles of detritus will in general be carried into the sea. The distance to which river-water, loaded with such particles, would flow over sea-water, must depend on a variety of obvious circumstances. Captain Sabine found discoloured water, supposed to be that of the Amazons, 300 miles distant in the ocean from the embouchure of that river. It was about 126 feet deep. Its specific gravity was = 1.0204, and the specific gravity of the sea-water = 1.0262. This appears to be the greatest distance from land at which river-water has been detected at the surface of the ocean.†

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* See Book of Science, pt. i. pp. 125; and 158.

† De la Beche's Geol. Researches, p. 72.

The quantity of detrital matter conveyed by rivers to the sea, must be greatly influenced by the nature of the countries through which they take their course. The Hoang-ho, or Yellow River of China, flows through alluvial tracts, and the quantities of mud and earth carried down by its current gives the water the appearance of diluted clay. According to Mr. Barrow, it pours into the sea every hour, 2000 feet of solid earth, sufficient in seventy days, if accumulated on one spot, to form an island a mile in circumference; and it has been observed, that a sensible diminution takes place in the depth of the Yellow Sea, into which the turbid river discharges itself. The additions of land that have been made in the Netherlands, along the shores of the North Sea; in Italy, on the borders of the Adriatic;* and in Egypt, at the mouth of the Nile; together with many other phenomena of a similar nature have been noticed by historians and geologists.†

The alluvial matter conveyed to the sea by great rivers may not only produce deltas or additions of land to the coast, but also give rise to insular formations. This has taken place at the mouth of the Ganges, which during the flood season pours into the gulf such a quantity of mud and sand, that the sea only recovers its transparency at the distance of sixty miles from the shore. Hence an island has arisen opposite the mouth of the Hoogly river (one of the branches of the Ganges), and immediately south of Saugur Island, four miles from the nearest land of the delta. It is said to have been discovered in 1816, together with the canal dividing it from Saugur. It is situated 21° 35′ N. latitude, and 88° 20′ E. longitude, from Greenwich; its position agreeing with that assigned to the Bank of Saugur. A lighthouse has been erected on this spot, which is named Edmonston Island. For many years it has been covered with shrubs and herbage; but the whole surface was inundated for some hours during the flood in May, 1833, the light-keepers having escaped destruction by ascending into the lantern. Its dimensions before that time were stated to be two miles from east to west, and half a mile from north to south; but it was reduced in size by the inundation, and must have since been enlarged."*

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* According to Strabo, Ravenna, in the time of Augustus, stood among lagunes, as Venice does now, and at present the former city is a league distant from the shore.

† See Cuvier's Theory of the Earth, pp. 123—132.

Dr. Hutton ascribed the formation of valleys on the surface of the earth to the erosive action of rivers, as a general cause;† and though the more extensive observations of subsequent inquirers render his conclusions questionable, there can be no doubt but in some situations valleys may be thus produced. The effect of flowing water must depend on its rapidity and consequent impetus; and hence compact rocks occasionally have their surfaces ploughed with gullies and hollows by the power of mountain streams. Dr. Bigelow, in describing the White Mountains in New Hampshire, N. A., says, "In several places a broad continued stripe descended the mountains, having the appearance of a regular road cut through the trees and rocks from near the base to the summit. On examining these with a telescope they were found to be channels of streams, and in several places the water could be seen dashing down the rocks.

"In a plain near the base of the mountains was a pond of one or two acres, situated near the road, and, which having no other inlet or outlet appeared to be the principal source of the Saco river. The waters of this stream, being collected from several sources, proceed directly towards the side of the mountain. At the point where, to all appearance, they must be intercepted in their course, there occurs one of the most extraordinary features of the place, well known by the name of 'the Notch.' The whole mountain, which otherwise forms a continued range, is here cloven quite down to its base, affording a free opening to the waters of the Saco, which pass off with a gradual descent towards the sea. This gap is so narrow that space has with difficulty been obtained for the road, which follows the course of the Saco through the Notch to the eastward. In one place the river disappears, being lost in the caves and crevices of the rocks, and under the shelves of the adjoining precipice, reappearing at length at the en-

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[*] Monthly Magazine—Lyell's Prin. of Geol., vol. i. p. 354.

[†] See De Luc's Elementary Treatise on Geology, translated from the French, by the Rev. H. De la Fite, 1809, p. 89.

tance of some rods below. The Notch gradually widens into a long narrow valley."[*]

It appears that the upper part of the rock was gneiss and granite; and near the Notch, chiefly coarse reddish jasper, and porphyry.[†]

The manifest effect of lakes must, in general, be formative, rather than destructive, contributing to the production of new strata, by moderating the influence of running water, and furnishing cavities for the deposit of detrital matter. But the bursting of the banks by which lakes are restrained may occasion inundations and debacles, causing important modifications of the surface of a country.

Such would take place, as already remarked, if Lake Erie was to have its outlet cut backwards to its border from the Falls of Niagara; and, if this work of ages were completed, the valley which now constitutes the basin of the lake would be traversed by a large river.[‡] The operations of nature, however, are generally gradual; and a concurrence of circumstances would be requisite to cause the sudden evacuation of the contents of a large lake. A remarkable accident of this kind took place in 1818, in consequence of the bursting of a lake formed in the Valley of Bagnes, in the Vallais. This valley, situated five leagues from St. Branchier, is very narrow at one end, where a ravine is formed by Mont Mauvoisin on the south side, and Mont Pleureur on the north; the latter, which is the highest, presenting a rocky surface above 500 feet in altitude, capped by the immense glacier of Chedroz. Large blocks of ice often falling from these heights accumulate continually in the valley, through which passes the river Drance, fed by the waters of more distant glaciers. The stream had formed for itself a bed under the mass of ice and snow; but in the winter of 1818, the glacier, which had been gradually increasing, dammed up entirely the passage by which the river made its exit. The waters were thus retained within the valley, forming an immense lake, confined on one side only by the wall of ice. On the 14th of May the lake was 7200 feet in length, and 630 in breadth, its greatest depth being 180 feet. The government of the canton of Vallais, to prevent as far as possible the ravages to be apprehended from a sudden inundation, had an artificial gallery 700 feet in length, cut through the ice, 50 feet below the level of the lake. This was completed in time to carry off a large portion of the water, reducing it from about 800,000,000 to 530,000,000 cubic feet. But on the approach of the hot season, the central part of the remaining wall of ice gave way, with a tremendous crash, and the lake was emptied in half an hour; the flood sweeping away trees, houses, bridges, and large masses of rock, some of which were of enormous size. It desolated the plains of Martigny, and afterwards passed on with diminishing velocity till it entered the Rhone, on whose current the bodies of some men who had been drowned were carried a distance of about thirty miles, to the further side of the lake of Geneva, near Vevay.

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[*] *Abstract of an Account of the White Mountains.* By Jacob Bigelow, M.D.—Brande's Journal of Science, vol. ii. p. 393.

[†] Idem, p. 397.

[‡] See De la Beche's Geolog. Man., pp. 59—61.

In 1595, an inundation took place in the Valley of Bagnes, owing to precisely the same cause with that of 1818. It destroyed the villages situated on the banks of the Drance, and carried away a great part of the town of Martigny.*

When deposits take place of sand or other substances, transported by rivers into the basins of lakes, the effects will be analogous to those before noticed, as resulting from depositions on the bed of the sea. Islands in general will first appear above the surface of the water, which uniting with each other, and then with the land constituting the banks of the lake, must at length produce a level tract, intersected by the stream to whose action it owed its origin. Such formations must in most instances be gradual and protracted; but indications of their progress have frequently been observed. De Saussure, in his "Travels among the Alps," mentions having obtained several very fine views of the Lake of Neufchatel. "We were struck," says he,

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* Brande's Journal of Science, vol. v. pp. 372—374; and Edinb. Philos. Journ., vol. i. p. 187, &c.

Mr. Bakewell, in noticing the catastrophe of 1818, says, "From the quantity of mud and stones which the current bore along, it resembled a moving mass of stones and earth. An English gentleman, who was descending the valley at the time, observed his horse exhibit by its motions great trepidation, of which he could not discover the cause, until a loud rushing noise occasioned him to look back, when he beheld what appeared like a wall, filling up the bottom of the valley, and advancing rapidly towards him. He instantly alighted, and scrambled up the adjacent rocks, leaving his horse to his fate."—*Introd. to Geol.*, p. 508.

"upon first beholding it, with the great extent which it must formerly have had; for the spacious, marshy, and horizontal meadows by which it is bounded on the south-west, have unquestionably been at some period covered by its waters. We shall have occasion to make the same remark with respect to the other bank of the lake."* The alluvial land here mentioned, according to De Luc, still increases, but now very slowly: the first deposits, on the contrary, accumulated rapidly, from the abundance of debris encountered by the waters originally, when likewise their courses were less tortuous than at present.†

"The higher part of the Lake of Como is nearly filled up by the detritus transported by the Adda and Mera.‡ The former has divided the lake into two; the smaller portion (known by the name of Lago di Mesola) being so shallow, from the united deposit of the two rivers and some torrents, that aquatic plants grow through the water on the eastern part; while on the western, in which there is a greater depth, the process of filling up is hastened by means of stones, detached in such numbers, in particular seasons of the year, from the heights on that side, that a passage in a boat beneath the cliffs becomes exceedingly hazardous."§

The accumulation of solid matter in the basins of lakes, and the gradual transformation of lakes into rivers, are well described by Professor Playfair, and exemplified in the progressive changes observable in the lakes of Westmorland and Cumberland.‖ But it is unnecessary to multiply instances of such phenomena, the nature of which may be sufficiently understood from the details already given.

The destructive effect of water in the degradation of the surface of the earth, is obvious in the occurrence of those phenomena called Landslips. Accidents of this sort may be produced by the weight of quantities of water percolating through porous strata, and collecting in communicating cavities at various depths, in consequence of which thick masses of rocks may be disrupted by the force of hydrostatic pressure.* Water also may find its way to beds of argillaceous or calcareous earth, between rocks composed of denser matter, highly inclined, and producing disintegration of the connecting strata, the superincumbent masses may fall by their own weight. Circumstances of this kind have repeatedly occurred in different parts of the Alps. In 1248, a portion of Mont Grenier, south of Chambery, in Savoy, fell, and buried five parishes, including the town and church of St. Andrew, the ruins covering the space of about nine square miles, called *les Abymes de Myans*; which, notwithstanding the lapse of so long a period, still exhibits a singular scene of desolation.† Pleurs, a considerable town in the Grisons, with the neighbouring village of Schelano, was thus destroyed August 26, 1618. On that day an inhabitant entered the town, and told his neighbours that he had seen the mountains cleaving; but he was only laughed at for his information. However, in the evening the town and all its inhabitants, except this person, were overwhelmed by the fall of a vast mass of rock from the south side of the mountain of Corto, which had been loosened by percolated water. A part of the mountain near Servoz, on the road to Chamouni, fell down in 1751. The descent of the mass did not take place in this case at once, as happened at Mont Grenier; for the mountain, consisting of a succession of beds of limestone resting on sandstone, and extremely fragile schist, gave way by degrees. For many days a succession of reports, like those of cannon, announced the continued falling of the rocks, day and night; and the air was filled with vast volumes of black dust, extending twenty miles. The rocks still appear to be subject to the constant action of rain; and in 1821 Mr. Bakewell noticed appearances indicating the probability of a renewal of the catastrophe of 1751. Three villages, with their inhabitants, were entirely destroyed in 1772, when the mountain of Piz fell, in the district of Treviso, in the Venetian territory.‡ The fall of the mountain called Rossberg or Ruffiberg, in Switzerland, took place September 2, 1806. It is 5196 feet above the level of the sea, and is situated opposite to Mont Righi. At five in the evening, the Knippenbuhl Rock, which formed the summit of the mountain, was on a sudden detached from its station, carrying with it part of the mountain a few feet in thickness on the western side, and about 280 feet on the eastern side, which rolling into the valley that separates the lake of Zug from that of Lauwertz, overwhelmed the entire villages of Goldau, Rothen, Busingen, Huezloch, and three-fourths of that of Lauwertz. The fall of a portion of the mountain into the lake of Lauwertz, filled up about one-fourth part of it, and caused such an inundation as overthrew a number of houses, chapels, mills, and other buildings, on the southern shore of the lake. Enormous masses of rock are said to have been carried through the air to prodigious distances. The rocks in falling brought down great quantities of earth, together with large blocks of flint, which were thrown on the opposite bank of the lake, to the height of from 80 to 100 feet. In the villages overwhelmed not an individual escaped destruction; and eight or nine hundred persons fell the victims of this disaster. The structure of the Rossberg sufficiently accounts for the occurrence, which General Pfiffer is reported to have predicted twenty years previously. Its upper part is composed of beds of a compound rock, formed from the debris of the Alps at an antecedent geological period; and these being porous, admitted the percolation of water arising from rain and melted ice and snow, which softening the clay between the more solid strata, inclined at an angle of about 45°, a slide took place, and they were precipitated into the valley below.* A large portion of mountain, consisting of rocks and soil, covered with fir-trees, separated from the highest region of the Alps, on the 4th of April, 1818, near the village of Soncebos, in the valley of St. Imier, in Switzerland; and covered with its stupendous wreck more than three hundred paces of the great road to Brienne. A party of travellers witnessed this terrific catastrophe, who, had they been a few moments later, would have been its victims.†

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* Voyages dans les Alpes, sect. 390.

† Treatise on Geology, p. 160.

‡ See Sections and Views illustrative of Geological Phenomena, by Mr. De la Beche, pl. 31.

§ De la Beche's Geol. Man., p. 53.

‖ See Illustrations of the Huttonian Theory of the Earth, Edinb. 1802, p. 357.

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* See Book of Science, part i. p. 129.

† See Bakewell's Introd. to Geol., pp. 463—466, where the account of the fall of Mont Grenier is illustrated by a cut, representing the present state of the *Abymes de Myans*.

‡ Malte-Brun's Geography, vol. i. p. 435.

Partial alterations of the surface of a country may be produced by deluges of mud, owing to the bursting of peat-mosses and bogs. In December, 1772, Solway Moss, having been filled with water during heavy rains, rose to an unusual height and then burst. A stream of black thick mud flowed over the plain, like a current of lava; overwhelming some cottages, and covering 400 acres of land; but fortunately without occasioning the loss of human life. The highest parts of the original moss subsided about twenty-five feet, and the lowest part of the country submerged was full fifteen feet deep.*

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* Nicholson's Journal of Natural Philosophy, 8vo, vol. xv. pp. 150—152.

† Brande's Journal of Science, vol. v. p. 377.

A similar phenomenon occurred more recently on the confines of Yorkshire and Lancashire. On the 2d of September, 1824, at Haworth, five miles south of Keighley, in the West Riding of the county of York, and on the borders of Lancashire, about six o'clock in the evening, a part of the highlands on the Stanbury Moor opened into a chasm, and sunk to the depth of six yards, in some places exhibiting a ragged appearance, and forming two principal cavities—the one was about two hundred yards, and the other not less than six hundred yards in circumference. From these hollows issued two immense volumes of muddy water, which uniting at the distance of upwards of one hundred yards from their sources, constituted, for about two hours, an overwhelming flood from forty to fifty (sometimes seventy) yards in width, and seldom less than four yards in depth. This dark slimy mixture of mud and water followed the course of a rivulet, overflowing its banks for twenty or thirty yards on each side, and to the distance of seven or eight miles from the immediate eruption; all this way there was deposited a black moorish substance, varying from eight to thirty-six inches in depth, and mixed occasionally with sand and rocky fragments, pieces of timber, and uprooted trees, which had been borne along by the impetuous torrent. This heavy and powerful stream broke down one solid stone bridge, made breaches in two others, clogged up and stopped several mills, laid flat and destroyed many fields of corn, and overthrew to the foundation several hedges and walls. In its course it entered the houses, floating the furniture about, to the astonishment and terror of the inhabitants. At the time of the eruption the clouds were copper-coloured, and lowering; the atmosphere was strongly electric, and unusually close and sultry. There was at the same time loud and frequent thunder, with much zigzag lightning, peculiarly flaring and vivid. An hour before there was scarcely a breath of air stirring, but the wind quickly rose to a hurricane; and after blowing hard from six to eight o'clock, sunk again into a profound calm, at which time the heavy rain, which had continued all the while, ceased, and, with the exception of a few floating clouds, the sky was very serene. Part of the torrent of mud passed into the river Aire, rendering its stream turbid at Leeds, and causing the destruction of great quantities of fish.*

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* Lyell's Principles of Geology, vol. iii. p. 137.

A still later inundation, from the bursting of a peat-moss, happened in the county of Sligo, in Ireland. After a sudden thaw of snow, in January, 1831, the bog between Bloomfield and Geevah gave way, and a black deluge flowing in the direction of a small stream, swept along heath, timber, mud, and stones, and overflowed several meadows and tracts of arable land. Passing through a piece of bog, the flood traced a wide and deep ravine, and carried away completely two hundred yards of a solid road.†

The destructive action of water in consequence of its congelation by cold is sometimes exhibited on a very extensive scale. In cold climates the disintegration of rocks is caused by the freezing of water, which having insinuated itself into crevices in its utmost state of condensation, afterwards expands in the act of forming ice. Loud reports, owing to the rifting of rocks from this cause, frequently attest the magnitude and violence of the effects produced; and thus large masses of rock with superincumbent glaciers are torn from the summits and sides of mountains, and fall in desolating avalanches into the vales below. When large rivers are frozen and a sudden thaw comes on, great blocks of ice floating on the swollen current, may be driven against its banks and cut away from them considerable portions, which falling into the water may obstruct its passage and cause floods, or even alter the course of a stream. The destructive operations of icebergs when drifted against maritime cliffs and precipices may obviously be productive of considerable modifications of the coast of a country, causing the fall of vast masses of rock and soil, to be afterwards disintegrated and scattered by the waves of the sea.

The influence of waves, breakers, and ocean currents, both in the degradation of land and in the formation of new strata beneath the water, contributes, perhaps, more than any other cause, to the alterations that are taking place on the superfices of the earth. Their destructive effect is more immediately obvious when they act on cliffs composed more or less of soft materials, and rising somewhat abruptly above the level of the sea; and hence the configuration of coasts will greatly depend on the relative hardness of the rocks of which they are composed. Thus the waves sometimes form bays or inlets by washing away portions of land; and where their action is resisted by more dense materials, they produce only a partial effect. Yet the most solid rocks may in time give way, and in the progress of destruction, influence the formation of ocean caves, or produce detached masses rising from the bosom of the deep, and presenting a variety of fantastic forms.

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* Times Newspaper.

† Lyell's Principles of Geology, u. s.

Dr. Hibbert, enumerating the effects of the waves on the coasts of the Shetland Islands, says, "The most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears to have been left as a sort of rampart against the inroads of the ocean; the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery, the waves having, in their repeated assaults, forced themselves an entrance. This breach, named the Grind of the Navir, is widened every winter by the overwhelming surge that, finding a passage through it, separates large stones from its sides, and forces them to a distance of no less than 180 feet. In two or three spots, the fragments that are detached are brought together in immense heaps that appear as an accumulation of cubical masses, the product of some quarry."*

The same writer gives instances of the destruction of islands, "until at last they become mere clusters of rocks, the last shreds of masses once continuous." Such was the origin of the granitic rocks called the Drongs, between Papa Stour and Hillswick Ness; and of a singular cluster of rocks, of a similar nature, to the south of the latter island.

The power of the sea when agitated is especially remarkable in overturning and drifting vast blocks of solid rock. Stevenson states that at the depth of two hundred feet the action of the sea is sufficient to break rocks in pieces, and throw them upon the coasts in masses of various forms and dimensions. He observes that "armerous proofs of the sea being disturbed to a considerable depth have occurred since the erection of the Bell Rock lighthouse, situated upon a sunken rock in the sea, twelve miles off Arbroath, in Forfarshire. Some driftstones of large dimensions, measuring upwards of thirty cubic feet, or more than two tons weight, have, during storms, been often thrown upon the rock from the deep water. These large boulderstones are so familiar to the lighthouse-keepers at this station, as to be by them termed travellers." *

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* Description of the Shetland Islands, Edinb. 1822, p. 528.

The effects of the more protracted action of waves and breakers is abundantly remarkable on various parts of the English shores, and in few situations more so than on those of Suffolk. The gradual destruction of the once extensive, flourishing, and populous city of Dunwich, has been noticed by several writers. "Gardner, in his history of the borough, published in 1754, shows, by reference to documents, beginning with Domesday Book, that the cliffs at Dunwich, Southwold, Eastern, and Pakefield, have been always subject to wear away. At Dunwich in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery—at another of several churches—afterwards of the old port—then of four hundred houses at once—of the church of St. Leonard, the high road, town-hall, the gaol, and many other buildings, are mentioned, with the dates when they perished. It is stated that in the sixteenth century, not one quarter of the town was left standing; yet the inhabitants, retreating inland, the name was preserved, as has been the case with many other ports, when their ancient site has been blotted out. There is, however, a church of considerable antiquity still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea cliffs, is well described by Gardner, with the coffins and skeletons exposed to view—some lying on the beach, and rocked

'In cradle of the rude impetuous surge.'

Of these cemeteries no remains can now be seen. Ray also says,

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* See Memoirs of the Wernerian Society, vol. iii.

'that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea.'* This city, once so flourishing and populous, is now a small village, with about twenty houses, and one hundred inhabitants."†

The action of tides and currents must be taken into the account, in estimating the influence of the sea in producing modifications of the surface of the globe. Tides are chiefly felt on the coasts, and their effects must be in a great degree similar to those above described; but the operation of currents may cause a variety of changes in the bed of the sea, in some places scooping out hollows, and in others heaping up wide tracts, or where from particular causes their direction has undergone alteration, sweeping away and dispersing the sand-beds produced by former currents. There are currents of various descriptions, the most important being those which appear to be permanent. Such are the Gulf Stream, and other branches of the great equinoctial current; the Polar or Greenland current, flowing strongly through Hudson's Bay and Davis's Strait; a current, which sets eastward into the Mediterranean Sea; and another that flows out of the Baltic, into the German Ocean. Besides these, there are a considerable number of periodical and temporary currents, the transporting power and effects of which must vary with circumstances.

Such are some of the more general and widely-operating causes of the modifications of the earth's surface, which have taken place within the period of historical record; but there are others, which are rather of a local nature, though their effects may in some cases be very extensive, and are often extremely striking and important. Among these are chemical deposits from fresh water, marine formations, either from chemical deposition or the work of coral polypes; and volcanoes and earthquakes. All these are highly interesting, and might furnish materials for several volumes; but among the numerous topics that remain to be considered, they can here only obtain a passing notice.

Some thermal springs contain siliceous earth, held in solution by their waters, and deposited on cooling. Such are the Geysers in Iceland, previously mentioned. Their deposits extend over an area of about half a mile in diameter; and from the depth of a cleft near the Great Geyser, the siliceous matter appears to be more than twelve feet in thickness. The hot springs of Furnas, in the volcanic district of St. Michael, one of the Azores, deposit large quantities of clay and silex, enveloping grass, leaves, and other vegetable bodies. Dr. Webster found "branches of the ferns which now flourish in the island completely petrified, preserving the same appearance as when vegetating, excepting the colour, which is now ash-grey. Fragments of wood occur, more or less changed; and one entire bed, from three to five feet in depth, is composed of the reeds so common in the island, completely mineralized, the centre of each joint being filled with delicate crystals of sulphur."* The deposits are both abundant and various, frequently forming horizontal strata. In the cavities of the deposits occur siliceous stalactites often two inches long, and covered with small brilliant quartz crystals. Compact masses, broken from various causes and cemented again by siliceous matter, form breccia, the elevations of which, in some places, Dr. Webster estimates at more than thirty feet.

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* Consequences of the Deluge—Physico-Theological Discourses.

† Lyell's Principles of Geology, vol. i. pp. 403, 404.

There are hot springs at Washita, in North America, in a non-volcanic district, which deposit a very copious sediment, consisting of silex, lime, and iron; and the thermal springs of Pinnarkoon and Loorgootha, in the East Indies, contain silica and various salts of soda.

Travertin, or calcareous tufa, is another deposit from springs; and though it is most common in limestone districts it is by no means confined to them, occurring indiscriminately in all rock formations. In Auvergne, in France, where the primary rocks are unusually destitute of limestone, springs abundantly charged with carbonate of lime rise up through the granite and gneiss. Again, in the valley of the Elsa, which skirts the Apennines in Italy, are innumerable springs, which have thrown down such calcareous precipitates, that the whole ground in some parts of Tuscany is coated with travertin, and sounds hollow under foot. A most striking instance of the rapid deposit of carbonate of lime from thermal waters may be observed in the hill of San Vignone, near Radicofani, and a few hundred yards from the high road between Sienna and Rome. A large mass of travertin descends the hill from the point whence the spring issues to the bank of the river Orcia, a distance of 250 feet, forming a mass of varying thickness, but sometimes 200 feet in depth; and on the other side of the hill a similar deposit extends about half a mile in parallel strata, one of which is 15 feet thick, and constitutes excellent building stone. Thermal springs, which yield calcareous deposits, are found in several parts of Italy, as the famous baths of San Filippo, on a hill a few miles from that last mentioned; the Bulicami, or hot baths, in the vicinity of Viterbo; a thermal spring, lately discovered near Civita Vecchia, which forms alternate beds of a yellowish travertin, and a white granular rock, resembling statuary marble; the Lake of Solfatara, in the Campagna between Rome and Tivoli; and calcareous formations are taking place in the waters of the river Velino, at Terni and in those of the Anio, which produces the travertin of Tivoli.[*] Calcareous deposits from springs have been noticed in Bohemia, Hungary, Mount Caucasus, Persia, and in various other parts of the world. Mr. Mantell mentions an incrusting or lapidescent spring, at Pounceford, in Sussex;[†] and such occur in Gloucestershire, and in other districts where there are formations of limestone.

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* Edinburgh Philos. Journ., vol. vi.

Precipitates of carbonate of lime are produced from the waters of some lakes; but there are others which yield deposits of a differe nature, though on a comparatively contracted scale. Bog-iron ore is sometimes found at the bottom of lakes and peat-mosses; and its origin is somewhat problematical. "It has been suggested that iron being soluble in acids, may be diffused through the whole mass of vegetables when they decay in a bog, and may, by its superior specific gravity, sink to the bottom, and be there precipitated so as to form bog-iron ore; or where there is a sub-soil of sand or gravel, it may cement them into ironstone, or ferruginous conglomerate."[‡]

In salt lakes considerable depositions of salt (chloride of sodium take place; and such collections of water being dried up or drained the sides and bottoms of the basins are found incrusted with salt sometimes constituting beds alternating with beds of clay. In S

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[*] See Lyell's Princ. of Geol., vol. i. pp. 296—310.

[†] Geology of the South-East of England, 1833, p. 223.

[‡] Lyell's Princ. of Geol., vol. iii. p. 331. See Rev. Dr. Rennie's Essays on Peat, p. 347.

Africa salt is obtained from such natural basins; and bay salt is the product of salt-pans or basins formed by art.

Carbonate of soda is precipitated in considerable quantities from the waters of a lake in Venezuela;[*] and similar deposits occur in other places.

Gypsum, or sulphate of lime, which forms one of the beds in the great Paris basin, and must therefore have been deposited most copiously at some distant period, now appears to be confined to a very few springs. Those at Baden, near Vienna, which supply the public bath, may be cited as examples. Some of them yield from 600 to 1000 cubic feet of water an hour, and throw down a fine powder, consisting of a mixture of sulphate of lime with sulphur and muriate of lime (chloride of calcium).[†]

In the island of Trinidad there is an extensive pitch-lake, the surface of which in wet weather is sufficiently hard to support heavy weights; but during the heats it approaches to a state of fluidity. This phenomenon, together with the existence of springs of naphtha and asphaltum in different quarters of the globe, may serve in some measure to elucidate the origin of bituminous shales, which occur in the geological formations of different ages.

The destructive influence of the waves of the sea is frequently exerted within the range of observation, so that we may in many cases be able to appreciate the effect produced with tolerable accuracy. But the formative or constructive operations of the ocean, which are carried on upon the most extensive scale, are in general entirely hidden from our view. We have abundant reason to believe that many of the strata which compose the crust of the terrestrial globe were formed by deposition from sea-water, and that analogous formations are now in progress; but with respect to the latter, we are obliged to speculate in the dark, those processes of nature in general taking place at unfathomable depths beneath the surface of the ocean. "As dwellers on the land, we inhabit about a fourth part of the earth's surface; and that portion is almost exclusively the theatre of decay, and not of reproduction. We know, indeed, that new deposits are annually formed in seas and lakes, and that every year some new igneous rocks are produced in the bowels of the earth, but we cannot watch the progress of their formation; and as they are only present to our minds by the aid of reflection, it requires an effort both of the reason and the imagination to appreciate duly their importance. It is therefore not surprising that we imperfectly estimate the result of operations invisible to us; and that, when analogous results of some former epoch are presented to our inspection, we cannot recognise the analogy. He who has observed the quarrying of a stone from a rock, and has seen it shipped for some distant port, and then endeavours to conceive what kind of edifice will be raised by the materials, is in the same predicament as a geologist, who, while he is confined to the land, sees the decomposition of rocks, and the transportation of matter by rivers to the sea, and then endeavours to picture to himself the new strata which Nature is building beneath the waters."*

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[*] A curious account of the manner in which soda is collected from this lake by the Indians, written by M. Palacio Faxar, may be found in Brande's Journ. of Science, vol. i. p. 188, &c.

[†] Lyell's Princ. of Geol., vol. i. p. 311; from Essai sur la Constitution Physique du Bassin de Vienne, par C. Prevost, p. 10.

The rocks formed under the surface of the sea originated either from mechanical deposition, or from chemical precipitation. Those of the former class are numerous, including most of the stratified rocks which inclose sea-shells, fragments of corals, and other exuviæ or bones of marine animals. Among those of the latter class, some geologists have reckoned even granite,† the origin of which, as well as that of all other unstratified rocks has, however, been more generally ascribed to igneous fusion and consolidation. Most of the calcareous rocks containing marine shells, must have been produced under the influence of chemical affinity; and of this nature are the formations which are occasionally observed to take place on the sea-coasts. Collections of perfect and broken sea-shells and corals are sometimes consolidated by the precipitation of calcareous and ferruginous matter, constituting banks or beds of considerable extent; and such masses containing shells occur on various parts of the shores of Great Britain. Similar conglomerates, including both shells and corals, are not uncommon around some of the islands in the West Indies. At Guadaloupe human bones have been found imbedded in a rock of this kind, whence were obtained two imperfect human skeletons, one preserved at the British Museum, and the other in the Museum of Natural History, at Paris; and from the occurrence of these bones and other circumstances, may be inferred the comparatively modern origin of the rock in question.

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* Lyell's Princ. of Geol., vol. i. pp. 117, 118.

† "The strata of granite," says De Luc, "evidently produced by chemical deposition from a liquid, form, as I have said, the most ancient monument of the action of physical causes on our globe."—*Element. Treat. on Geol.*, p. 4 This writer, however, doubtless imagined the primitive ocean (capable of holding in solution the substances which constitute granite) to have been a liquid of a different nature from the waters of the present ocean.

Among the marine formations there are few more curious or interesting than coral reefs and islands, which to a certain extent are constructed by different kinds of polypiferous zoophytes,* or minute animals, for whom the coral tubes serve as habitations. It has been supposed that the coral rocks descend in perpendicular columns to the bed of the ocean, and cover millions of acres of the Pacific;† but though the extent of such formations is very considerable, it appears to have been overrated.

M. Chamisso, who accompanied as a naturalist the expedition of discovery sent out by the Russian government, under the command of Captain Kotzebue, visited several groups of coral islands, arranged in a circular or oval form, with openings among them which afforded access to the interior basin. These islands seemed to be only the upper portions of ridges of unequal heights, on the inside of which, towards the basin or lagoon, where there is still water, the smaller and more delicate kinds of polypes carry on their operations, while the stronger species live and work on the exterior margin of the bank, against which a great surf usually breaks. These creatures leave off building as soon as their structures reach such a height as to be left almost dry at the lowest ebb of the tide. A continuous mass of solid stone is seen composed of shells of molluscs and echini, with their broken-off prickles and fragments of coral cemented by calcareous matter. The ridge is raised by fragments of corals thrown up by the waves, till it becomes so high as to be covered only by high tides and at certain seasons. Masses of the stone thus formed are sometimes separated and thrown upon the surface of the reef, so as gradually to augment its elevation. The calcareous sand on the top now furnishes a soil in which seeds of trees and plants brought by the waves vegetate rapidly, and overshadow its dazzling white surface. "Entire trunks of trees, which are carried by the rivers from other countries and islands, find here at length a resting-place after their long wanderings: with these come some small animals, such as lizards and insects, as the first inhabitants. Even before the trees form a wood, the sea-birds nestle here; strayed land-birds take refuge in the bushes: and at a much later period, when the work has been long since completed, man appears, and builds his hut on the fruitful soil."[*]

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* "Of the numerous species of zoophytes which are engaged in the production of coral banks, some of the most common belong to the genera *Meandrina*, *Caryophillia*, and *Astrea*, but especially the latter."—*Lyell's Princ. of Geol.*, vol. iii. p. 221.

† "The reefs in the Pacific are sometimes of great extent: thus the inhabitants of Disappointment Islands, and those of Duff's Group, pay visits to each other by passing over long lines of reefs from island to island, a distance of six hundred miles and upwards. When on their route, they present the appearance of troops marching upon the surface of the ocean."—*Lyell's Princ. of Geol.*, vol. iii. p. 235; from Malte-Brun's Geography.

MM. Quoy and Gaimard, who sailed in the French expedition more recently, under Captain Freycinet, also examined with attention the coral rocks and islands; and they were led to conclude that the polypiferous zoophytes do not begin building from any considerable depths below the surface of the sea, but merely produce incrustations a few fathoms in thickness; and that the appearance of these reefs and islands depends on the inequalities of the mineral masses beneath, the circular form of many of them indicating their foundation on the crests of submarine craters. It is supposed that those species of animals which chiefly contribute to the formation of coralline islands do not live in water at the depth of more than 30 feet; though the branched corals have been brought up in sounding off Cape Horn, in about [illegible] fathoms water, and Retepora have been found as low as 100 fathoms; but these do not form solid masses, though the ruins of their habitations might in time compose banks that would serve as platforms which the other species might make the foundations of their more compact structures.

Observations were made, during the recent voyage of Capt. Beechey to the Pacific, whence it may be inferred that the elevation of coral rocks proceeds in general very slowly; but a curious circumstance noticed by Mr. Lloyd, while engaged in his survey of the Isthmus of Panama, shows that bodies cast on submarine banks, where the coral animals are at work, may be very speedily cemented to the surface, and a considerable increase of height may hence take place in a short time. This gentleman, "seeing some beautiful polypifers on the coast, detached specimens of them; and it being inconvenient to take them away at the time, he placed them on some rocks or other corals, in a sheltered and shallow pool of water. Returning to remove them a few days afterwards, it was found that they had secreted stony matter, and fixed themselves firmly to the bottom. Now this property must greatly assist in the formation of solid coral banks; for if pieces of live corals be struck off by the breakers, and thrown over into calm water or holes, they would affix themselves, and add to the solidity of the mass."*

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[*] Lyell's Princ. of Geol., vol. iii. pp. 221, 222; from Kotzebue's Voyage 1815—1818, vol. iii.

It has been the subject of curious speculation whence the coral polypifers and testaceous mollusca can obtain the vast quantities of carbonate of lime, which they secrete to form the envelopes by which they are protected. Mr. Bakewell considers it as more than probable that they have the extraordinary faculty of producing lime from simple elements;† and Dr. Macculloch seems disposed to impute its origin, in the same manner, to the influence of vital energy, in combining elementary bodies.‡ If this were admitted, it would follow that the quantity of lime on the surface of the earth must be progressively increasing, unless it be supposed that other natural processes are regularly taking place for the decomposition of calcareous earth, or rather of its metallic basis calcium.

Mr. Lyell, in opposition to this doctrine, says, "We see no reason for supposing that the lime now on the surface, or in the crust of the earth, may not, as well as the silex, alumine, or any other mineral substance, have existed before the first organic beings were created, if it be assumed that the arrangement of the inorganic materials of our planet preceded in the order of time the introduction of the first organic inhabitants."§ He adds, in reference to the abundance of carbonate of lime furnished by springs which rise through granite,‖

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* De la Beche's Geolog. Man., p. 165.

† See Introduction to Geology, chap. vi. p. 110.

‡ System of Geology, vol. i. p. 219.

§ Principles of Geology, vol. iii. pp. 241, 242.

‖ See before, p. 326.

"But if the carbonate of lime secreted by the testacea and corals of the Pacific, be chiefly derived from below, and if it be a very general effect of the action of subterranean heat to subtract calcareous matter from the inferior rocks, and to cause it to ascend to the surface, no argument can be derived in favour of the progressive increase of limestone from the magnitude of coral reefs, or the greater proportion of calcareous strata in the more modern formations. A constant transfer of carbonate of lime from the inferior parts of the earth's crust to its surface, would cause throughout all future time, and for an indefinite succession of geological epochs, a preponderance of calcareous matter in the newer, as contrasted with the older formations." *

Earthquakes and Volcanos.

There are many circumstances which indicate such a connexion between earthquakes and volcanos, as may warrant the conclusion that they depend on the same general cause. Both these phenomena are manifestly owing to the agency of subterranean heat. Volcanic eruptions of lava in a state of igneous fusion, of red-hot stones and ashes, and of columns of steam, afford sufficient evidence of the very high temperature that must subsist in the interior of the earth. The phenomena of earthquakes, also, which seem to be owing to the sudden expansion of gases, vapours, and perhaps of solid matter, display equally characteristic effects of the influence of internal heat.

Earthquakes and volcanos frequently happen at the same time; and indeed an eruption of lava from a burning mountain, even when comparatively inconsiderable, can hardly take place without some agitation of the surface of the surrounding country; every volcanic paroxysm therefore, is probably attended with an earthquake, and the extent the commotion is usually proportioned to the violence of volcanic action. Those countries in which there are volcanos are more frequently visited by earthquakes than such as are distant from them. But the latter are by no means exempt from such visitations. Indeed there is perhaps no part of the earth's surface that may not be occasionally shaken; though there are many in which the experience -

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* Principles of Geology, u. a.

ages has led the inhabitants to regard such phenomena, so far as relates to themselves, rather as objects of curiosity than of alarm. Next to those countries which are the seats of open or extinct volcanos, mountainous districts, and especially those consisting of primary rocks, are the most frequent scenes of earthquakes; though secondary and tertiary hills, wide level tracts, marshes but little above the sea, sandy deserts and fertile fields are more or less exposed to their destructive operation. They occur in all climates, cold, temperate, or tropical; as is also the case with volcanos. Both kinds of phenomena appear to be more prevalent near the sea-coast than elsewhere: thus Syria, the coasts and islands of Asia, America, the countries bordering on the Mediterranean, and Iceland, have been repeatedly devastated by them; while the plains of Asia, Africa, and the north of Europe, experience comparative security. The occurrence of earthquakes is by no means unfrequent. Mr. Lyell observes, that Von Hoff has published from time to time, in a German journal, lists of the earthquakes which have happened since 1821; and from these it appears, that every month has been signalized by one or more convulsions in some part of the globe.* The recurrence of earthquakes, either where they are common or where they are slight and unfrequent, has not been observed to take place at any particular periods, nor to be influenced by the seasons of the year, and they happen sometimes by day and sometimes at night, and in various states of the atmosphere.†

The principal phenomena of earthquakes consist of tremblings and vibrations of the surface of the earth, extending to various distances, and often having a certain direction. These shocks begin in general with elevations of the ground, followed by horizontal undulations, and in some instances by violent irregular agitations, and by vortical or gyratory motions. To these may be added, the rending, slipping, rising and sinking of the soil and substrata; the sudden retreat of the sea, and its impetuous return, alternately laying bare the sands and beaches, and in its tremendous inroads on the shores, sweeping away trees, buildings, and other solid masses; the violent agitation of lakes, which sometimes sink into the earth; the drying up or bursting forth of springs and rivers; and the occurrence of inundations, from the fall of fragments of rock or soil, which may block up their channels.

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* Principles of Geology, vol. ii. p. 175.

† "It has been considered that earthquakes are presaged by certain atmospheric appearances, but it may be questionable to what extent this supposition is correct. Historians of earthquakes seem to have been generally desirous of producing effect in their descriptions, adding all that could tend to heighten the horror of the picture. They have not always, moreover, been anxious or able to separate accidental from essential circumstances. As far as my own experience goes, which is, however, limited to four earthquakes, the atmosphere seemed little affected by the movement of the earth; though I should be far from denying that it may be so, for we can scarcely imagine such movements to arise in the earth, without some modification or change of its usual state of electricity, which would affect the atmosphere. If animals be generally sensible of an approaching shock (as has been asserted), it might arise as well from electrical changes, as from the sounds which they may be supposed capable of distinguishing."—*De la Beche's Geol. Man.*, pp. 140, 141.

The distances to which the effects of earthquakes extend are very great. Thus when the terrible catastrophe of Lisbon happened in 1755, the shock was felt not only over nearly the whole of Europe, but also in the West Indies. The earthquake which visited the coast of Chili, November 19, 1822, is said to have been felt simultaneously throughout a space of 1200 miles from north to south. And in the same year Aleppo, in Syria, was destroyed by an earthquake, the influence of which extended from the banks of the Euphrates to the Island of Cyprus, in the vicinity of which two rocks are stated to have risen from the sea.

The duration of shocks has been variously estimated, from a few seconds to more than two minutes. It is probable, however, that single agitations seldom last more than half a minute, and are often of shorter duration; as may be concluded from the remarks of observers on those slighter shocks which occur in situations where the apprehension of danger is not likely to distract the attention. Though the shocks are sometimes single, yet it more frequently happens that they recur rapidly at various intervals; and in volcanic districts especially they have been repeated occasionally for months or years. The famous earthquake that desolated Calabria, in Italy, and extended across the strait to Messina, commenced in February, 1783, and the shocks continued till the close of 1786.

Among the phenomena caused by shocks, there are few more singular than those which result from the gyrations or rotatory movements which have been already noticed. During the earthquake of Calabria, the general direction of which was from south-east to north-west many statues were turned round on their pedestals, and a large mass of rock was turned 25° from the south towards the east. The same effect was more remarkably observable during the earthquake at Valparaiso, in November, 1822, when many houses are reported to have been turned round, and three palm-trees were found twisted together like the strands of a rope. Earthquakes are almost always preceded by unusual agitations of the waters of the sea and of lakes; and springs sometimes send forth torrents of fetid, dark mud. A noise immediately precedes the shock, which has been described as resembling the dragging of loaded waggons rapidly over a rough pavement, an irregular but sudden discharge of batteries of cannon, or the rushing of a hurricane.

The phenomena of slight shocks are probably in general very similar to those which were noticed when England was somewhat agitated by an earthquake in 1797. A person who was in bed at Gloucester, about midnight, and happened to be awake, observed an undulation of the surface of the ground, extending from south-west nearly to north-east, and the bedstead, which was placed in that direction, seemed to be slightly raised from foot to head, and sink again with a wave-like motion; while the agitation was sufficient to cause the sashes of the windows to rattle, much in the same manner as they do in consequence of the passing of carriages through those streets of London, where the excavations for vaults and sewers extend generally beneath the surface; and it was reported, that in some houses in Gloucester, plates, dishes, and other articles were thrown down from the shelves on which they had stood. The whole lasted not more than a few seconds.

The most remarkable phenomena of earthquakes in those countries where they do most damage have been already generally noticed. The Calabrian catastrophe of 1783, concerning which the particulars have been most fully and clearly recorded, is described at some length by Mr. Lyell;* and to his very interesting work the reader must be referred, for a variety of curious details relative to this subject.

Before we proceed to consider the influence of earthquakes in modifying the surface of the earth, and the different opinions that have been advanced as to the extent and importance of their effects, it will be requisite to take some notice of volcanos, with which they are so intimately connected.

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* See Principles of Geology, b. ii. pt. ii. chap. vii.; vol. ii. p. 197, &c.

The general description of volcanos is that of openings in the crust of the earth, through which are ejected, from time to time, various gases, cinders, ashes, stones, and streams of lava, composed of red-hot melted rocks. From the accumulation of matters thus discharged, conical eminences are formed, with funnel-shaped cavities called craters; and they generally occupy the summits of isolated peaks or mountains. They occur in all quarters of the globe, and are often distributed in groups over wide areas; as in the volcanic band which includes Sumatra, Java, the Moluccas, and the Philippine Islands; and the line of the Andes in America, extending from Chili, or perhaps from Terra del Fuego, to Mexico. They are often found near the shores of continents, or in islands; and hence it has been supposed that they have some necessary connexion with the sea. But recent researches have shown, that they also occur, though more rarely, at great distances from the ocean, or any considerable body of salt water. Volcanic mountains differ greatly in height. That of Esk Mount, in Jan Mayen's Island, between 70° 49′ N. lat. and 71° 8 is but 1500 feet above the sea-beach, in Jameson's Bay; Vesuvius is 3932 feet above the level of the sea; Hecla, in Iceland, rises to the height of 5000 feet; and that of Etna, in Sicily, is 10,870 feet: but the loftiest mountains are those of the Andes; as Pichincha, the height of which is about 15,931 feet; Cotopaxi has an elevation of 18,867 feet; and Antisana attains that of 19,136 feet. Volcanos occur in various latitudes, from Greenland and Kamtschatka to Sumatra and Columbia; nor is the sea by any means exempt from them, numerous islands having at different periods been raised by volcanic action from the bed of the ocean in different parts of the world, some of which have remained permanently above the waves, though most of those whose origin has been noticed have subsequently sunk, forming only submarine reefs and sandbanks.

The number of the volcanos now occasionally in activity has been stated by some to be about two hundred; though, according to others, they amount to rather more than three hundred, including solfataras or smoking volcanos. But besides those from which eruptions have issued within the period to which our records extend, there are many extinct volcanos, of which abundant traces remain in several countries. Thus in France, the territories of Auvergne, Vivarais, and the Cevennes, exhibit conical mountains, composed of lava, scoriæ, and volcanic ashes; and in some of them the forms of the craters may still be discovered. The district around the town of Olot, in Catalonia; and that of the Eifel and the Lower Rhine, in Germany, present similar appearances.

Some volcanos are perpetually active, as is the case with that of Stromboli, in the Mediterranean. It is mentioned by Pliny; and there is reason to believe that its eruptions have been almost incessant during the last two thousand years. According to Dolomieu, its crater does not exceed fifty paces in diameter. "I saw it dart," says that writer, "during the night, at regular intervals of seven or eight minutes, ignited stones, which rose to the height of more than 100 feet, forming radii a little diverging; but of which the greater number fell into the crater, while others rolled even to the sea. Each explosion was accompanied with a burst of red flame." Mr. G. P. Scrope, from personal observation on this volcano, states, that "there evidently exists within and below the cone of Stromboli, a mass of lava, of unknown dimensions, permanently liquid, at an intense temperature, and continually traversed by successive volumes of aëriform fluids, which escape from its surface—thus presenting exactly all the characters of a liquid in constant ebullition."*

Among those which may be styled intermitting volcanos, the most important are found amidst the Andes. Cotopaxi is the loftiest of these burning mountains, from which at recent epochs eruptions have proceeded. It is also the most dreadful of all those in the kingdom of Quito, and subject to the most frequent and destructive explosions. The mass of scoriæ, and the huge fragments of rocks thrown out of this volcano, cover a surface of several square leagues, and would form, were they heaped together, a colossal mountain. In 1758, the flames rose 2900 feet above the brink of the crater. In 1744, the roaring of the volcano was heard on the borders of the Magdalena, a distance of 200 leagues. On the 4th of April, 1768, the quantity of ashes ejected by the volcano was so great, that the inhabitants of the owns of Hambato and Tacunga, were obliged to use lanterns to walk he streets at noonday. The explosion, which took place in January,

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* Considerations on Volcanos, by G. P. Scrope, F.R.S.

1803, was preceded by the sudden melting of the snows that covere the mountain. For twenty years before, no smoke or vapour ha been observed to issue from the crater; and in a single night, the subterraneous fire became so active, that at sunrise the external walls the cone were heated to such a temperature as to appear quite naked and of the dark colour characteristic of vitrified scoriæ.*

One of the most dreadful volcanic eruptions on record, is that whic occurred in the mountain of Tomboro, in the island of Sumbaw eastward of Java, in April, 1815. It commenced on the 5th of Apr was most violent on the 11th and 12th, and did not cease entirely u July. Out of a population of twelve thousand persons, only twent six escaped destruction. Violent whirlwinds swept away men, hors cattle, and every thing which came within their vortex, tore up th largest trees, and covered the neighbouring sea with floating timb Large tracts of land were inundated by lava, several streams of wh issuing from the crater, reached to the sea. Vast clouds of volc dust and ashes, as before mentioned, were conveyed to immense d tances, blackening the air, and for a time eclipsing the sun. T floating cinders to the westward of Sumatra, formed on the 12th April a mass two feet in depth, and several miles in surface, thro which ships with difficulty forced their way.

A captain of a ship, who was at Macassar on the 11th of Ap says, "By noon, the light that had remained in the eastern part of horizon disappeared, and complete darkness had covered the fac day: our decks were soon covered with falling matter; the awn were spread, fore and aft, to prevent it as much as possible from g ting below; but it was so light and subtile, that it pervaded every of the ship. The darkness was so profound through the remainde the day, that I never saw any thing equal to it in the darkest ni it was impossible to see your hand when held up close to the eye. ashes continued to fall without intermission through the night. six o'clock the next morning, when the sun ought to have been it still continued as dark as ever; but at half-past seven I had satisfaction to perceive, that the darkness evidently decreased, an eight I could faintly discern objects on the deck. From this tim began to get lighter very fast, and by half-past nine the shore was distinguishable; the ashes falling in considerable quantities, though not so heavily as before. The appearance of the ship, when daylight returned, was most extraordinary; the masts, rigging, deck, and every part, being covered with the falling matter; it had the appearance of calcined pumicestone, nearly the colour of wood ashes; it lay in heaps of a foot in depth in many parts of the deck, and I am convinced several tons weight were thrown overboard; for, although a perfectly impalpable powder or dust when it fell, it was when compressed of considerable weight. A pint measure filled with it weighed 12¼ ounces; it was perfectly tasteless, and did not affect the eyes with any painful sensation; it had a faint, burning smell, but nothing like sulphur. By noon, on the 12th, the sun again appeared, but very faintly, through the dusky atmosphere, the air still being charged with the ashes, which continued to fall lightly all that day and the succeeding one."

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* Edinburgh Review, vol. xxiv. p. 142; from Humboldt's Researches cerning America.

Along the sea-coast of Sumbawa, and the neighbouring islands, the water rose suddenly from two to twelve feet, great waves rushing up the estuaries, and again retreating. At Bima, about forty miles westward of the volcano, though the wind was still during the whole time of the eruption, the sea rolled in upon the shore, and filled the lower parts of the houses with water a foot deep. Every prow and boat was driven from its anchorage, and thrown ashore. The perpendicular depth of the ashes that fell here was found to be 3¼ inches. The noise of the explosions, as heard from this place on the 14th, is said to have been most terrific, resembling the reports of a heavy mortar fired close to the ear. The town called Tomboro, on the western side of the volcano, was overflowed by the sea, which encroached upon the shore at the foot of the mountain, so as to leave the land permanently submerged to the depth of 18 feet.*

"The changes produced by such eruptions as that here recorded, would, independently of the alteration in the shape of the volcano itself, and of the streams of lava which flowed from it, extend to very considerable distances. On the dry land, vegetables and animals would be entombed beneath stones and ashes, the quantity of the covering matter probably increasing with the proximity of the volcano. And if it should chance, as sometimes happens, that the aqueous vapours discharged from the volcanic vent were suddenly condensed, the torrents produced would sweep away not only the looser parts of the volcano, but also the plants and animals which they might encounter, imbedding them in a thick mass of alluvial matter. The vegetable and animal substances enveloped by the discharged ashes, cinders, and stones, falling into the sea, would be both marine and terrestrial; and a very curious mixture, so far as regarded its organic contents, would be observed: trees, men, cattle, fish, corals, and a great variety of marine remains, would be incased, and it might so happen that, both on the land and in the sea, a bed of lava might cover such accumulations."[*]

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* Brande's Journ. of Science, vol. i.; Hist. of Java, by Sir T. S. Raffles, vol. i. p. 28, &c.; Life of Sir T. S. Raffles.

The quantity of solid matter ejected from some volcanos is immensely great. Vesuvius, Etna, and other volcanic mountains have at different times, discharged lava, cinders, and ashes, the total bulk of which would at least equal that of the mountains whence they issued. During one eruption of Etna, an area 150 miles in circumference is said to have been covered with a stratum of volcanic sand or ashes 12 feet deep. In 1775, the same volcano, according to Dolomieu, poured out a stream of lava, 12 miles in length, 1½ in breadth, and 200 feet in thickness. That writer also states, that some of the currents of lava from Etna are 10 leagues in length, and 3 in breadth.[†] But the most extensive known current of modern lava appears to be that formed by a volcano in Iceland, in 1783, which is 60 miles long and 12 broad, equalling in extent any continuous rock formation in England.[‡] The surface of the country for many leagues round Naples seems to be composed of volcanic matter. Herculaneum and Pompeii, which were covered by vast showers of ashes during the first recorded eruption of Vesuvius, A. D. 79, when they were partially disinterred in the course of the last century, were ascertained to have been founded on a volcanic rock, and their streets were paved, and some of their buildings constructed of blocks of lava, of uncertain but early origin.

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[*] De la Beche's Geol. Man., p. 132.

[†] Mémoire sur les Isles Ponces, &c., p. 166.

[‡] Bakewell's Introd. to Geol., p. 378.

The present cone of Vesuvius is supposed to have been formed since the eruption just mentioned. and the more ancient lavas to have flowed from the adjacent mountain, now called Somma. Near Puzzuoli, on the coast of the Bay of Baiæ, a mountain was thrown up suddenly, September 29, 1538, after repeated shocks of earthquake. Its present height is 440 feet above the level of the sea; and it is about 1½ miles in circumference. This volcanic cone is called Monte Nuovo; and at a short distance from it is another of more ancient date, and larger dimensions, named Monte Barbaro.

The phenomena of submarine volcanos resemble, in many respects, those of sub-aërial volcanos; the chief difference consisting in the more copious emission of aqueous vapour and gases, and in the formation of temporary or permanent islands. It is probable that Owhyhee, and many other islands in the Pacific, were formed in this manner; as also the Canary Islands, the Azores, and several others. Such likewise was the origin of the Lipari Islands, as we learn from history; and of some of those in the Grecian Archipelago, where a new island arose in 1707, called Nea [New] Kaimeni, near Santorin, which, as well as some of those adjacent, was thrown up at a more remote period.* Among the numerous instances on record of islands produced by submarine volcanos which have subsequently sunk beneath the surface of the water, one of the most recent occurrence was that, the elevation of which took place in July, 1831, between the Island of Pantellaria and the coast of Sicily. This has been circumstantially described by different observers; but for the highly interesting details we must refer to the annexed authorities.†

Some volcanos eject only gases and vapours, and these are called solfataras, or where the cones are very small, *fumarole*, and in Mexico, *hornitos*; others send forth torrents of water and mud, as is the case with the volcano of Macalubba, in Sicily, and frequently with the volcanic peaks of the Andes; but the more usual products of volcanic action are streams of lava, and showers of scoriæ, sand, and ashes, accompanied, however, by clouds of steam and gas. As to the composition of lavas, exact information is wanting. However, Mr. Phillips says, "it is nearly certain that feldspar and augite are the principal ingredients, and that the colour of the lava is dependent on the prevalence of the one or the other. The minerals which are discoverable as entering, in notable proportion, into the composition of volcanic masses, are very few; as feldspar, compact feldspar, augite, hornblende, oxidulous iron, olivine, mica, leucite; other minerals, indeed, are found in their cavities, but these can scarcely be said to enter into the composition of the rock."—"It is remarkable, that quartz, so extremely abundant in rocks of which the composition is not suspected to be of volcanic origin, is scarcely ever found in such as are decidedly volcanic."* It must, however, be observed, that Mr. Poulett Scrope enumerates among volcanic rocks, quartziferous trachyte, containing numerous crystals of quartz; and siliceous trachyte, having much silex in its composition.†

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* See Lyell's Principles of Geology, vol. ii. pp. 151—155.

† Philos. Transact. for 1832; Journ. of Geographical Society, 1831; Annales des Sciences Naturelles, tom. xxiv.; and Lyell's Principles of Geology, vol. ii. pp. 145—150.

As to the causes of volcanos and earthquakes, various opinions have been proposed, some of which appear to be quite inconsistent with the effect produced. Thus Werner and his disciples attributed them to the spontaneous combustion of beds of coal; and others imputed their origin to the inflammation of vast repositories of sulphur or petroleum collected in caverns of the earth; and the experiment of Lemery, noticed elsewhere,‡ has been alleged as affording an explanation of the manner in which sulphur and iron might take fire when buried in the earth. A more plausible hypothesis was proposed by Sir H. Davy, who having discovered that potash and soda were the oxides of highly inflammable metals, which become oxidated with the extrication of abundance of heat when they come in contact with water, sought to explain volcanic phenomena, by imagining the existence of large quantities of the metallic bases of the alkalis within the bowels of the earth, and their sudden oxidation through the access of sea-water to the cavities in which they were contained. This theory has been adopted and advocated recently by Dr. Daubeny, in his "Description of active and extinct Volcanos;" but it seems inadequate to the full development of the agency on which the vast power and extensive influence of these phenomena depends.

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* Outlines of Mineralogy and Geology, p. 264.
† Quarterly Journ. of Science, vol. xxi. 1826.
‡ See Treatise on *Chemistry*.

Earthquakes and volcanos may be supposed to have a common origin, since volcanic eruptions are generally preceded by agitations of the surface of the earth, such as would necessarily be caused by the efforts of heated and expanded fluids, either liquid or gaseous; and especially of the latter, embowelled in the earth, to escape through the superincumbent strata. It is true, that earthquakes happen frequently in countries where there are now no volcanos, and it may be admitted, that they sometimes are neither accompanied nor followed by volcanic eruptions: but this only proves, that the elastic force of expansive fluids confined within the earth, may not always be sufficiently powerful to overcome at once the resistance to their exit, and therefore they cause concussions of the surface; and accordingly it has been observed, that repeated earthquakes during longer or shorter periods have frequently preceded violent volcanic eruptions.

If, then, earthquakes and volcanos depend on the same causes, the source of these phenomena must be very deeply seated below the earth's surface: for though volcanos might be regarded as confined to certain localities, the action of earthquakes seems to be almost unlimited, since these concussions of the surface have been felt over nearly half the globe. Mr. Bakewell, in reference to the earthquake of Lisbon, the shock of which was perceived in the United States of America and the West Indies, observes that "the cause which could effect a simultaneous concussion over such a vast extent, must probably have been seated nearly midway between the centre of the globe and its surface."* Such widely-acting power cannot reasonably be ascribed to the topical agency of chemical affinities; and hence some bold speculators have inferred, that these phenomena are connected with the central fire, or rather with the candescent matter supposed to exist in the interior of the earth. Volcanos, therefore, are considered as vast safety-valves, by means of which some portions of the substances in fusion which form the internal mass escape, from time to time with violence, to flow over the surface of the soil.†

The electric influence, whatever may be its nature, cannot but be considered as one of the most powerfully active causes of the changes which have at former periods been produced in the surface of the earth, as well as of those which are now in progress. But notwithstanding the discoveries which have been recently made relative to electricity, and its connexion with magnetism, we are still too little acquainted with its mode of action to be enabled fully to appreciate the extent of its operations. There can be no doubt but the chemical combinations and decompositions of bodies on the surface of the earth must be greatly influenced by atmospheric electricity; and there is some reason for concluding that subterranean phenomena may depend on its mysterious agency. "Now the identity of magnetism and electricity seems, in many respects, to be established, it may deserve consideration, whether an interruption to the magnetic or electric currents which circulate through the earth, may not sometimes occasion earthquakes, acting almost instantaneously over large portions [illegible] the globe. If, as some philosophers maintain, there is a central [illegible] under every part of the globe, or if certain spaces only are filled with ignited matter, we can scarcely doubt that chemical changes are taking place, which will also change the electrical relations between [illegible] mineral beds. A series of strata may act like the plates of an immense voltaic battery, and discharge the electricity from one [illegible] part of the globe to another, exciting vibrations that may agitate whole hemisphere."*

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* Introduction to Geology, p. 373.

† Bertrand Lettres sur les Rev. du Globe, p. 69.

Researches concerning the extent and importance of the modifications of the earth's surface, which have resulted from the action existing causes, have led different philosophers to discordant conclusions relative to the nature of that agency which produced the [illegible] composing the crust of the earth, and occasioned the dislocations [illegible] changes they have undergone at far distant and unknown periods. While some assert the efficiency of the causes now in action, others represent them as inadequate and insignificant. With respect to the effects of winds, currents, and other modifying causes, [illegible] Conybeare thus expresses himself:

"These actions appear to be circumscribed within very narrow limits: over a great part of the earth's surface the influence of these wasting causes is absolutely null, the mantle of greensward that invests it being an effectual protection. The barrows of the aboriginal Britons, after a lapse of certainly little less, and in many instances probably more, than two decads of centuries, retain very generally all the pristine sharpness of their outline; nor is the slight fosse that sometimes surrounds them in any degree filled up. Causes, then, which in two thousand years have not affected in any perceptible manner these small tumuli, so often scattered in very exposed situations over the crests of our hills, can have exerted no very great influence on the mass of those hills themselves in any assignable portion of time, which even the imagination of a theorist can allow itself to conceive; and where circumstances are favourable to a greater degree of waste, still there is often a tendency to approach a maximum at which further waste will be checked: the abrupt cliff will at last become a slope, and that slope become defended by its grassy coat of proof. It should appear, that even the action of the sea, certainly the most powerful and important of all those we have surveyed, has a similar tendency to impose a limit to its own ravages. It has obviously in many instances formed an effectual barrier against itself, by throwing up shingle-banks and marsh-lands in the face of cliffs against which it once beat; and after the destruction has been carried to a certain point, it appears necessary from the mode of action (excepting where very powerful currents interfere), that the very materials resulting from the ruin should check any further increase: even where these currents exist, these also have a tendency to throw up barriers of shingle in their eddy. Historical records, and the very nature and physical possibilities of the case, alike compel us to dissent entirely from those crude and hasty speculations which would assign to the causes now in action, the power of producing any very material change in the face of things; and which would refer to these alone, acting under their present conditions, and with only their present forces, the mighty operations which have formed and modified our continents."*

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* Bakewell's Introd. to Geol., p. 275.

Mr. Conybeare does not here distinctly mention earthquakes and volcanos among the existing causes of alteration of the surface of the earth; and as he could not have overlooked their influence, it is probable that he regarded their action as being too limited to produce any considerable effect. Mr. De la Beche, who also asserts the dissimilarity of the ancient and modern modifying causes of terrestrial conformation, makes the following observations on the phenomena to which we have just alluded:

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* Outlines of the Geology of England and Wales, by Conybeare and Phillips, pt. i. 1822. Introduction, pp. xxxii. xxxiii.

"If we withdraw ourselves from the turmoil of volcanos and earthquakes, and cease to measure them by the effects which they have produced upon our imaginations, we shall find that the real changes they cause on the earth's surface are comparatively small, and quite irreconcilable with those theories which propose to account for the elevations of vast mountain ranges, and for enormous and sudden dislocations of strata, by repeated earthquakes acting invariably in the same line, thus raising the mountains by successive starts of five or ten feet at a time, or by catastrophes of no greater importance than a moderate earthquake. It is useless to appeal to time: time can effect no more than its powers are capable of performing: if a mouse be harnessed to a large piece of ordnance, it will never move it, even if centuries on centuries could be allowed; but attach the necessary force, and the resistance is overcome in a minute."*

Among those writers who have taken the opposite side of the question, and maintained the efficacy of causes now operating to have produced the more ancient modifications of the surface of the earth, Mr. Lyell has distinguished himself by the learning and ability displayed in support of the opinions he has adopted. The full force of his arguments can only be appreciated by those who have the opportunity of examining the extensive mass of information which he has collected in his treatise on "The Principles of Geology."† The following are some of the important remarks and inferences which he has deduced from the consideration of existing phenomena, and of the degree of analogy observable between ancient and modern formations:

"It is undeniable that many objections to the doctrine of the uniform agency of geological causes have been partially or entirely removed by the progress of the science in the last forty years. It was object-for example, to those who endeavoured to explain the formation of sedimentary strata by causes now in diurnal action, that they must take for granted incalculable periods of time. Now the time which they required has since become equally requisite to account for another class of phenomena brought to light by more recent investigations. It must always have been evident to unbiassed minds, that successive strata, containing, in regular order of superposition, distinct beds of shells and corals, arranged in families as they grow at the bottom of the sea, could only have been formed by slow and insensible degrees in a great lapse of ages: yet, until organic remains were minutely examined and specifically determined, it was rarely possible to prove that a series of deposits met with in one country was not formed simultaneously with that found in another. But we are now able to determine, in numerous instances, the relative dates of sedimentary rocks in distant regions, and to show by their organic remains that they were not of contemporary origin, but formed in succession."—"We cannot reflect on the concessions thus extorted from us, in regard to the duration of past time, without foreseeing that the period may arrive when part of the Huttonian theory will be combated on the ground of its departing too far from the assumption of uniformity in the order of nature. On a closer investigation of extinct volcanos, we find proofs that they broke out at successive eras, and that the eruptions of one group were often concluded long before others had commenced their activity. Some were burning when one class of organic beings were in existence, others came into action when a different and new race of animals and plants existed: it is more than probable, therefore, that the convulsions caused by subterranean movements, which seem to be merely another portion of the volcanic phenomena, have also occurred in succession; and their effects must be divided into separate sums, and assigned to separate periods of time. Nor is this all: when we examine the volcanic products, whether they be lavas which flowed out under water or upon dry land, we find that intervals of time, often of great length, intervened between their formation, and that the effects of single eruptions were not greater in amount than those which now result from ordinary volcanic convulsions. The accompanying or preceding earthquakes, therefore, may be considered to have been also successive, often interrupted by long intervals of time, and not to have exceeded in violence those now experienced in the ordinary course of nature."—"It was contrary to analogy to suppose that Nature had been at any former epoch parsimonious of time and prodigal of violence—to imagine that one district was not at rest, while another was convulsed—that the disturbing forces were not kept under subjection, so as never to carry simultaneous havoc and desolation over the whole earth, or even over one great region."*

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* Geolog. Man., pp. 148, 149.

† See especially Book II., contained in the 1st and 2d vols. of the edition.

It must be impossible to form any correct judgment as to the relative probability of these conflicting estimates of the influence of those natural causes now in action on the structure and conformation of the crust or exterior portion of the terrestrial globe, without a previous acquaintance with the observations that have been made on the visible phenomena of the early formations, and the displacements and modifications to which they have evidently been subjected. Hence it will be requisite to take some notice of the great convulsions of the surface which have left indelible traces of their occurrence; and also to give a brief description of the usual appearances of rocks, and of their modes of consolidation, stratification, and juxtaposition.

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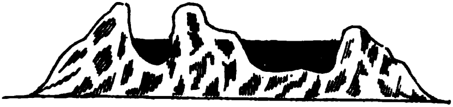
* Princ. of Geol., vol. i. pp. 126—129. As an argument for the probability that ancient deluges were owing to causes similar to those now in operation, Mr. Lyell observes that "the existence of enormous seas of fresh water, such as the North American lakes, is alone sufficient to assure us, that the time may come, however distant, when a deluge may lay waste a considerable part of the American continent." Mr. Conybeare, in a paper published in the "Annals of Philosophy, 1830 and 1831," endeavours to invalidate the reasoning of Mr. Lyell, by a comparison of the effect produced by the cataract of Niagara, with the erosive action of the current of the Thames, in scooping out the valley through which it flows, alleging that according to the fluviatile hypothesis of the formation of valleys, that of the Thames must have been hollowed out by that river, in the course of the same period of time during which the waters of the lakes have only worn a channel seven miles in length. But M. Boué remarks that "the hollowing out of the valley of the Thames and its lateral banks, commenced not merely since the tertiary epoch, but long anterior to it, since the valley traverses very different formations; whilst on the contrary, the cataract of Niagara was formed in the alluvial modern or Jovian period of M. Brongniart." Previously to that epoch he alleges that the American lakes emptied themselves into the Mississippi, and that the course of their outlet was changed by volcanic phenomena, of which there are still some traces in Canada and the northern United States. See a French translation of Mr. Conybeare's "Examination of those Geological Phenomena which appear to have the most immediate Connexion with Theoretical Opinions," by M. Boué, with Notes, in his "Mémoires Geologiques," vol. i.

Excavation of Valleys, Denudation of Surfaces, and Elevation of Mountains and Continents.

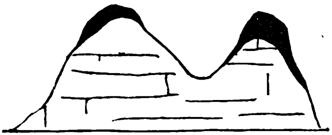
The great diversity of appearance of the surface of the earth is caused chiefly by the occurrence of valleys and mountains; and an inquiry into the circumstances of their formation, so far as they can be ascertained from existing appearances, may serve materially to enable us to appreciate the nature of the power by which they were originally produced or subsequently modified.

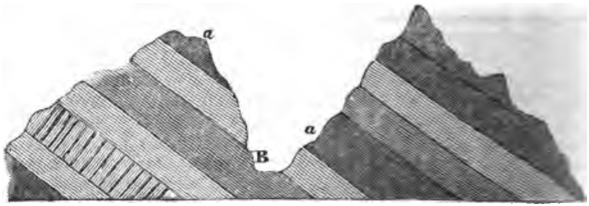
Valleys have sometimes been distinguished into two classes, termed Natural Valleys and Excavated Valleys. The origin of the former is ascribed by Werner to original inequalities of the deposits which form the surface of the earth. Valleys of this kind might originate from the gradual desiccation of a lake; and precipitations of solid matter from the water might obviously take place, without causing any considerable alteration of the figure of the basin. For the depositions might form strata of equal thickness on the bottom and sides of the cavity, so as only to lessen its size; or if the water dried away very gradually, the deepest deposit would be in the centre, and the basin might still preserve nearly the same outline.

It may easily be conceived, however, that the deposit may be so arranged as to cover the bottom of the lake, fill up any irregularities, and alter more or less the form of the cavity, rendering it shallower, and in place of a deep lake, leaving a valley with a level surface at the bottom. The subjoined figure exhibits sections of two valleys of different extent, the lighter part marking the outline of the solid rock, and the darker the deposits of gravel and detritus which have partly filled the cavities. Such valleys, where the superficial strata are undisturbed, may be regarded as being coeval with the formation of the tract in which they are situated.



Excavated Valleys, or Valleys of Erosion, exhibit very different appearances. These occur in hilly and mountainous countries, while the former may be found in the midst of extensive plains. The excavation of valleys may take place under a variety of circumstances, producing corresponding irregularities of conformation. When strata which were once continuous are broken and swept away by a torrent of water, if the beds were arranged horizontally, the opposite sides of the valley would present similar rocks at the same elevation; while the alluvial soil or looser deposits would form the summits of the adjacent eminences, as represented in the marginal figure. Sometimes, however, the appearances are very different. The opposite strata of a valley not being arranged horizontally, but inclined at a certain angle, beds of the same rock form ascending lines on one side and descending lines on the other, as may be perceived in the following figure.





In this section it will appear, that the stratum *a*, which forms the summit of the hill on one side of the valley B, descends to the basis of the hill on the opposite side of the same valley. Instances of this kind a unfrequently occur; and they are obviously owing to the different beds having been tilted or upraised simultaneously by an earthquake or some other convulsion of nature, previously to the scooping out the valley, and removal of those portions of once continuous strata which had occupied its site.

When the beds thus cut through and partially swept away consist of well characterized rocks, such as would be recognised without difficulty, if found in masses, either large or small, far from the strata still remaining *in situ*; and when such shapeless fragments are found at a distance from the former, it may naturally be concluded that they, at some preceding period, filled the now open space. If, then, it appears that these detached masses have not sharp angles and edges, but are worn and rounded, it must be inferred, especially if the rock be hard and compact, that the blocks or pebbles had been subject to violent attrition against each other, in the course of their long and distant transport; and that the same deluge that had occasioned their disruption, or exposure to subsequent action of a similar description, had reduced them from an angular to an oval or globular shape, like the water-worn pebbles on the sea-beach.

Now there are to be met with in many countries on the surface of the earth masses of different sizes, and of every variety of rock: some of these are large and angular, as is the case with the vast blocks of granite strewed over the surface of several parts of Germany, and which have been referred to the granitic chains of the Norwegian and Swedish mountains, as their original position. Other portions of transported matter are small and rounded, as may be observed with respect to the gravel so largely used for the repair of the roads in the vicinity of the metropolis, and which is found in thick and extensive beds. This gravel is almost entirely flint, formerly contained in the chalk strata, which seem to have once covered nearly the whole of the south-eastern part of England, from some districts of which it has been carried away, at a distant period, by a great flood or floods, which softened and washed off the lighter chalk, leaving the more compact and heavier flints behind.

Great masses of rock and transported gravel are found in the north of England. Professor Buckland observed among the gravel of Durham twenty varieties of slate and greenstone, which do not occur, *in situ*, nearer than the lake district of Cumberland. He also mentions a large block of granite at Darlington, of the same nature with that at Shap, near Penrith; and other blocks of this granite are found in different parts of Durham.* Professor Sedgwick notices large trans-

* Buckland's Reliquiæ Diluvianæ.

ported boulders on parts of the Derbyshire chain of hills overhanging the great plain of Cheshire. He observed boulders and pebbles at the base of the Cumberland mountains, which must have been transported across the Solway Firth, from Dumfriesshire. On a hill near Hayton Castle, about four miles north-east from Maryport, there are large granitic boulders resembling the rocks of the Criffel; and among them a spheroidal mass, in one direction, 10½ feet in diameter. Vast multitudes of transported, or as they have been termed *erratic blocks*, are found scattered over the northern counties of England.

The blocks of Shap granite, which cannot be confounded with other rocks in the north of England, are not only drifted over the hills near Appleby, but have been scattered over the plain of the new red sandstone; rolling over the great central chain of England into the plains of Yorkshire; imbedded in the transported detritus of the Tees; and even carried to the eastern coast.*

In Scotland, likewise, such blocks abundantly occur, and in some remarkable situations; as in the Shetland Islands, where there are boulders, which do not correspond with any known rock in the country, and which were probably derived from the northward. It seems likewise that similar phenomena are observable in the Feroe Islands.†

"The probability, therefore," says Mr. De la Beche, "as far as the above facts seem to warrant, is, that masses of water have proceeded from north to south over the British Isles, moving with sufficient velocity to transport fragments of rock from Norway to the Shetland Isles and the eastern coast of England; the course of such masses of water having been modified and obstructed among the valleys, hills and mountains, which they encountered; so that various minor and low currents having been produced, the distribution of detritus has been in various directions."‡

The continents, both of Europe and North America, frequently present analogous phenomena of erratic blocks and transported gravel. is difficult to account for the occurrence of erratic blocks, particularly in certain situations, from which it must be inferred, that they have been carried across the sea, and sometimes to great distances. It been conjectured that these massive bodies might have been imbedded in ice, and thus conveyed by currents which would have failed to remove them had not their specific gravity been thus diminished. Other hypotheses have been proposed to account for these phenomena, but they are not sufficiently probable to require further notice; and we shall only remark, in the words of a distinguished writer, that "solutions of the problem of erratic blocks seem not very practicable at present."

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* De la Beche's Geol. Man., pp. 187, 188.

† Dr. Hibbert, in Edinb. Journ. of Science, vol. vii.

‡ Geolog. Man., p. 189.

In some districts, immense tracts of strata several hundred feet in thickness have been torn from the inferior surface, and the materials all carried off, except some occasional patches, forming the caps of isolated hills, the analogous composition of which shows that they were once parts of a continuous formation. These extensive removals of superficial strata have been termed Denudations, of which phenomena Great Britain presents numerous instances; one of the most remarkable of which is that called the Denudation of the Valley of the Weald, including the district between the North and the South Downs, chiefly in the county of Sussex. The geology of this tract has been rendered highly interesting by the researches and important discoveries of Mr. Mantell, relative to the fossil remains imbedded in some of the strata; which will be subsequently noticed. The Wealden country is bordered on three sides by chalk hills, which terminate abruptly on its confines, and which appear to have once extended over the intermediate space. "The theory advanced by Mr. Farey, to explain Denudations, was, that the surface had been broken and swept away by the near approach of a comet. But the most rational explanation that can be offered, is that which ascribes the effect to a mighty deluge, sweeping over the surface of the globe, tearing off part of its crust, and transporting the fragments into distant regions, or into the ocean."*

The origin of valleys has sometimes been attributed to those convulsions of the earth which occasion the elevation of mountain ridges; and some valleys must doubtless have been thus produced, however they have been subsequently modified by the action of the atmosphere or of running water. "If the crust of the globe were broken, and raised in parallel ridges, they might form mountain ranges, with valleys between them, like what are observed bordering the central range of the Alps; the arched stratification of many of the calcareous mountains, and the vertical position of the beds favours this hypothesis."

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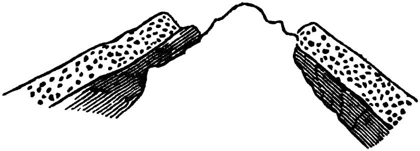
* Bakewell's Introd. to Geol., p. 516.

The production of mountains has been ascribed to different causes; but the most obvious and important seems to be elevation in consequence of some force acting from beneath. Volcanic action has in numerous instances formed mountain cones and peaks, consisting of deposits of scoriæ, ashes, and lava. But there are many situations in which granitic and other primary rocks, constituting in general the lowest strata of the crust of the globe, have been raised in a solid state, so as now to form the summits of lofty mountains. Long chains or ridges of hills, which occur in various parts of the world, cannot originate from the immediate influence of volcanic eruptions. Such elevations of solid matter, and extensive ridges, therefore, must be supposed to be owing to the operation of causes such as those which occasion earthquakes, or rather, in fact, to be the result of earthquakes taking place on a most stupendous scale.



The manner in which the more dense and solid masses of primary rocks may be forced up, and made to break through the less compact strata of clay, gravel, or other substances, by pressure from below, and thus form the summit of a mountain ridge may be understood from the marginal figure. Here the irregular conical mass in the centre, which may be supposed to be granite, gneiss, or primary limestone, is represented as having burst asunder the superior strata, which now form the sides of the mountain. Wherever strata originally horizontal exhibit a vertical or highly-inclined position, the sudden and violent operation of an elevating force may be inferred; and where mountains are raised to a considerable height, and preserve an unbroken range of nearly horizontal strata, it must be concluded that the upheaving force was slow in its operation, or acted on a large segment of the earth's surface.

The elevation of large continents and entire islands must, like that of mountains, have been owing to the action of a force from below but the magnitude of the effect produced, and the difference of the phenomena, show that there must have been a considerable diversity in the mode of operation. Probably all large tracts of country or continents emerged slowly from the ocean, at first forming islands, before the lower tracts were raised above the level of the sea. The power requisite to upheave a continent, or in other words, to cause the protrusion of a large portion of the solid surface of the earth, must be very different from the force which, acting in certain lines, occasioned the elevation of mountain ranges. This country affords instances of the apparent difference between the modes of action of those forces which raised ridges of hills, and those which elevated continents or extensive islands. "The elevating force that broke and tilted up the chalk strata and the tertiary strata, along a line extending east and west through the Isle of Wight, into Dorsetshire, does not appear to have produced any considerable change on each side of the line. In passing from Alum Bay, where the chalk strata are nearly vertical, to the south side of the island, it is truly extraordinary to observe how little the lower beds beneath the chalk, and adjacent to it, appear to have been disturbed. The force which uptilted the strata is altogether distinct from that mighty upheaving force, which raised the whole chalk hills in the south of England from the ocean, without disturbing the relative position of the strata."*

Some extraordinary elevations of land are said to have taken place at very recent periods. Von Hoff states that, in 1771, several tracts of land were upraised in Java, and that a new bank made its appearance opposite the mouth of the river Batavia. It has also been asserted, that it appeared on the morning after the earthquake in Chili, in 1822, that "the whole line of coast, from north to south, to the distance of above 100 miles, had been raised above its former level." The accuracy of the observations on which these statements are founded have, however, been questioned by Mr. Greenough: but this celebrated geologist admits that it is a point deserving of consideration, "whether there may not be going on, in the calmest seasons and in the stillest countries, *a chronic and almost imperceptible impulsion of land upwards*;" and he refers to the researches of the Swedish philosophers concerning the decreasing height of the waters of the Baltic, as affording some evidence that such an operation is in progress.*

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* Bakewell's Introd. to Geology, pp. 500, 501.

The evidences of both elevation and depression, in former times, are abundantly demonstrative. The occurrence of beds of oysters and other sea-shells on the tops of mountains and on elevated plains, shows that the land must at some distant period have been submerged; and the remains of forests seen beneath the surface of the sea off the coasts of Yorkshire, Lincolnshire, and in other parts of the world, indicate the changes that have taken place of a contrary description. It is manifest, then, that some portions of the earth's surface have been depressed, and what was once dry land has become the bed of the sea, while other parts formerly covered by its waters, and resorted to by marine crustacea, have been since upheaved into hills and mountain ridges, thickly strown with the exuviæ of their ancient inhabitants.

The earth seems to be subject to a kind of oscillation of surface; one area of which may be reduced below the level of the ocean at one period, and another at another. All the rocks which have originated since this globe became the scene of organic life, afford evidences of their having been deposited under a liquid, except the volcanic and trap rocks, the igneous origin of which cannot be doubted. That granite, gneiss, primitive quartz, and limestone, with the other non-fossiliferous rocks, were produced in the same manner with those last mentioned, may also be admitted as at least probable. These rocks form, as it were, the skeleton or basis of the solid crust of the earth, and they appear to be the most widely and continuously distributed. In the rocks of this class are chiefly found the metallic ores and most valuable minerals. The superior rocks or strata are more especially interesting on account of the bodies they contain, either curious or useful, derived from organic matter.

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* See the Athenæum Journal for June 14, 1834, No. 346, for interesting extracts from the Address delivered by Mr. Greenough, as President to the Geological Society, at their last meeting of the session, June 4.

General Structure and Composition of Rocks, and their Modes of Juxtaposition.

The different kinds of rocks may be distinguished as respects their mineralogical composition and their mechanical structure. Considered as mineral bodies, they are either simple or compound. Thus there are some that consist essentially of a single mineral, as Quartz Rock, which is composed of quartz or siliceous earth; and Primitive Limestone, and Chalk, which both consist of carbonate of lime.

The minerals that enter into the composition of rocks are by no means numerous; and of these the most important are included in the following catalogue:[*]

1. Argillaceous Earth (Indurated Clay) [242].[†]
2. Siliceous Earth (Quartz) [243].
3. *Steatite*[‡] [245].
4. Feldspar [247].
5. Albite, or Cleavelandite [247].
6. Mica [248].
7. Chert, or Hornstone [244].
8. *Pitchstone* [247].
9. *Talc* [248].
10. *Chlorite* [248].
11. Hornblende [248].
12. Serpentine [248].
13. *Actinolite* [248].
14. *Augite* [249].
15. *Diallage* [249].

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[*] See Dr. Macculloch's Geological Classification of Rocks, 1821, p. 166; and Phillips's Outlines of Mineralogy and Geology, p. 88.

[†] The numbers annexed to the names of the different minerals indicate the pages of the preceding treatise on *Mineralogy*, in which they are respectively described.

[‡] Those minerals, the names of which are printed in italics, are comparatively of unusual occurrence, or are found in relatively small proportions in those rocks of which they are ingredients.

16. *Hypersthene* [249].
17. *Garnet* [249].
18. *Schorl* [251].
19. Carbonate of Lime—Chalk [257].
20. Carbonate of Magnesia [260].
21. Gypsum [265].
22. Oxide of Iron.
23. *Bitumen.*
24. Coal.

Besides some of the minerals in the preceding list, Mr. Philip mentions the following, as being sometimes interspersed in rocks, o occasionally forming masses in them: Iron Pyrites [236], Sulphure Molybdena [239], Oxidulated Iron [240], Oxide of Tin [242], Fl [244], Calcedony [244], Jasper [245], Obsidian [247], Calcare Spar [258], Dolomite [260], and Arsenical Iron [262]. The writer has given a list of minerals most frequently occurring in vei These are Carbonate of Barytes [257], Phosphate of Lime [262], S phate of Barytes [265], Selenite [265], and Fluor Spar [267]; besid several ores of iron, manganese, copper, lead, and zinc, informa concerning which may be found in the treatise on *Metallurgy* a *Mining* in this volume.

It will appear from the preceding statements, that the mineral s stances which contribute most largely to the composition of roc amount to about a dozen; and these must obviously deserve the pr cipal attention of the geologist. Those that are more rare should however, be neglected, as their presence sometimes serves to iden particular kinds of rocks, and furnish their discriminating characte

The interest and importance of the various rocks to the geolo depends greatly on their relative situation, as contributing to form t crust of the earth. Of all the lower, or, as they are termed, primi rocks, the most important is granite, which is considered as a comp or non-stratified rock, and is thus distinguished from gneiss, t mineral composition of which is similar, but which is composed of tinct strata, and has been therefore sometimes styled stratified grani granitic slate. "Granite," according to Mr. De la Beche, "is a co fusedly crystalline compound of quartz, feldspar, mica, and ho blende." But there are various kinds of granite, some rocks denominated containing only feldspar and mica, others feldspar and quartz, feldspar and hornblende, or quartz and hornblende. But though all such might be termed granitic rocks, the appellation of granite should rather be restricted to compounds of feldspar, quartz, and mica. This rock, forming a most excellent architectural material, has been abundantly used in the buildings and pavements of the metropolis, and in other places, so that its general appearance needs not to be described; and it is, perhaps, unnecessary to add, that it constitutes the balustrades and side-pavements of Waterloo Bridge. In some specimens of granite the three characteristic minerals are in very small crystals, intimately and generally blended into a grey mass; in others, on the contrary, the crystals, particularly those of the feldspar, are extremely large, and in greater proportion than common. Red granite, which is found in Scotland, contains much feldspar, which is of a red or flesh colour, instead of being white, as usual. Graphic granite consists of quartz and feldspar only, the crystals of the latter being so distributed amidst those of the quartz, as to give the surface of the rock, when broken, the appearance of being covered with antique characters.

Diallage Rock consists either of the mineral from which it takes its name alone, or of diallage and feldspar, forming a granular crystalline compound. The former variety is rare, but the latter abounds in some of the Shetland Islands. There are other varieties, which contain actinolite, talc, chlorite, quartz, or mica.

Greenstone is a granular rock, chiefly composed of hornblende and feldspar, but sometimes including quartz, and occasionally calcareous spar.

Serpentine consists essentially of the mineral of that name, but sometimes contains hornblende, and also veins of steatite, talc, or asbestus. It is commonly of a dark green colour, intermixed with red, with waving lines, and convolutions on its surface.

Syenite is a compound of feldspar, hornblende, and quartz, confusedly aggregated, the former generally predominating. It derives its name from Syene in Upper Egypt, where however, it is said, the rock is of a different nature. It is usually very hard, and of a dull red colour, as the rock at Mount Sorel, in Leicestershire, but it is sometimes grey, or dark green.

Among the other unstratified rocks may be mentioned Schorl Rock, composed of schorl and quartz, and Hypersthene Rock, containing feldspar or albite, and sometimes quartz.

Porphyritic rocks vary in composition, but they are usually of a reddish or purple colour, and contain crystals imbedded in a mineral mass, as if they had been inclosed when it was in a semifluid state. "Porphyries are generally known by the name of the base or paste which includes the disseminated crystals: thus we have claystone porphyry, feldspathic porphyry, and clinkstone porphyry."*

The stratified rocks are commonly supposed to have been formed from the detritus of the unstratified rocks, taken up and afterwards deposited by water; unless where they consist of single minerals, as limestone and quartz, which must have been produced by chemical precipitation. The following are the inferior stratified or non-fossiliferous rocks described by Mr. De la Beche:† Argillaceous or Clay Slate, Chlorite Slate, Talcose Slate, Quartz Rock, Hornblende Rock and Slate, Primitive Limestone, Compact Feldspar, or Eurite, Mica Slate, Gneiss, and Protogine. The nature and general composition of most of these rocks is indicated by their appellations; gneiss, as before stated, is a stratified or schistose granite, and protogine differs from it only in containing talc or steatite, instead of mica.

The superior rocks may here be dismissed with a cursory notice. Grauwacke, or greywacke,‡ has been described as an aggregate cemented by ferruginous clay, and composed of the debris of the primitive rocks."§ The inclosed fragments are sometimes small and granular and sometimes as large as a nut.

Transition Limestone is so named to discriminate it from the other calcareous rocks, and particularly from the inferior or primitive limestone. The term *transition* is derived from the school of Werner, who regarded all rocks as having been produced by deposition from a liquid, and considering those which contain no organic remains (as granite or gneiss), to be the oldest, he gave the appellation of *transition rocks* to the immediately superincumbent masses, in which occur remains of zoophytes, and other petrifactions of the relics of the lower orders of organized beings, but none of vertebrated animals, or of any of the higher orders. Hence, also, he concluded that the rocks thus constituted were formed while the earth was in a state of transition from a comparatively uninhabitable to an inhabitable condition. Among the calcareous rocks also are Carboniferous Limestone, Magnesian Limestone, and Muschelkalk, or Shell Limestone, besides others.

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* De la Beche's Geol. Man., p. 447. † See Geolog. Man., sect. 1.

‡ The rock was thus named by a German miner, who was accustomed to term every rock he was unacquainted with *wacké*, and he distinguished it by the epithet *grau*, grey, from its colour.

§ Mawe's Familiar Lessons on Mineralogy and Geology. 12th edit. p. 78.

Red Sandstone exhibits great diversity of texture, sometimes forming a reddish or variegated marl or clay, and sometimes compact stony masses; in either case exhibiting streaks of light blue, verdigris, or cream colour.

Shale includes all the argillaceous schists of the secondary class, sometimes improperly called slate clay. These rocks seldom form extensive beds, but are found in thin strata, often of mere laminæ, alternating with the other rocks with which they are associated. Shale occurs together with coal, with which it likewise alternates, and it frequently contains organic remains.*

Lias is a term derived from the English miners, to denote an argillo-calcareous deposit, occurring in England and other parts of Western Europe, above the red sandstone, and below the chalk, forming, according to the arrangement of Mr. De la Beche, a portion of the Oolitic group, so called from the oolite, or roestone,† which constitutes the upper part of the group, while the lias forms its base.

The Trap, or Overlying Rocks, are unstratified, and are supposed to be the products of ancient volcanos. They occur in masses, generally irregular, and in outline presenting the appearance of steps, whence the appellation of *trap*, which is of Swedish origin. Dr. Macculloch calls them *overlying* rocks, doubtless because they are in most instances found resting on almost every other kind of rock, from chalk to granite. They are abundant, and sometimes form considerable mountains, though upon the whole they are of more limited extent than the stratified rocks.

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* See Dr. Macculloch on the Classification of Rocks, pp. 455—463.

† See Treatise on *Mineralogy*, p. 259.

Basalt is a designation applied to various dark-coloured rocks, of a close fine-grained texture. It resembles greenstone, and some writers describe it as composed almost wholly of hornblende, others of augite, feldspar, and titaniferous iron. Olivine is sometimes contained in it, and also quartz, calcedony, calcareous earth, and other substances. Basalt exhibits a columnar structure, and becomes porous on the exterior surface, from partial decomposition.

Wacke resembles indurated clay, often highly ferruginous, and is either compact or cellular. It appears to be basalt in a state of decomposition. Greystone, Porphyry Slate, and Clinkstone have been considered as varieties of either basalt or greenstone.

Trachyte is generally composed of feldspar, and sometimes contains albite. It is chiefly porphyritic, from included crystals of hornblende, mica, augite, sphene, and sometimes other minerals.

Amygdaloid is a trap rock, the basis of which is indurated clay, or compact feldspar. Various minerals, as agate, quartz, mesotype, analcime, stilbite, prehnite, carbonate of lime, green earth, lithomarge and iron pyrites, are occasionally imbedded in this rock, rendering it porphyritic; and their disintegration or decomposition produces a vesicular structure, giving it the appearance of cellular lava.

Pitchstone, which is considered by some as a semivitrified basalt has been found to contain a considerable proportion of bitumen.

Cornean is a term which has been used to denote a kind of rock the composition of which appears to be undetermined. It sometimes approaches to the characters of basalt, being very hard, and in other cases more closely resembles wacke. Brongniart conceived it to be the basis of the Derbyshire toadstone.

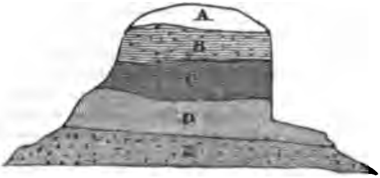
Traptuff is composed of the debris of the other rocks of this class united by an argillaceous cement, and forming a coarse breccia.

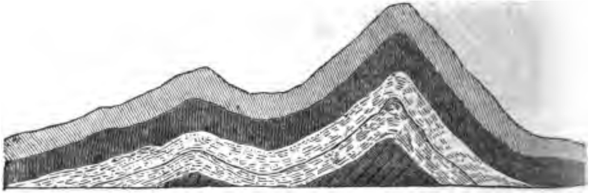
The principal compounds which are the products of modern volcanos are porphyritic and basaltic lavas, obsidian or volcanic glass pumice or porous lava, volcanic conglomerate, and volcanic tufa. The minerals contained in these more recent igneous rocks have been already noticed.

The mechanical structure of rocks admits of distinctions with regard to their internal texture, or their external appearance. It will be sufficient to enumerate the designations of interior structure by which different rocks are characterized. These are the stony, compact, earthy, granular, fibrous, lamellar, foliated, schistose, cellular, prismatic, amygdaloidal, porphyritic, and conglomerated varieties of conformation.

With reference to their exterior structure and appearance, rocks might be distinguished into those which are symmetrical, and those which are amorphous. Both these terms, however, must be employed with a considerable degree of latitude. Among the symmetrical rocks may be reckoned those which are stratified, tabular, or columnar; and all the other descriptions of rocks may be regarded as amorphous, or rather polymorphous, their external forms depending on incidental circumstances.

Stratified rocks are those in which masses of similar composition, as clayslate or sandstone, extend through a hill or mountain in nearly parallel layers or strata. They display in different situations great varieties of arrangement and juxtaposition. Sometimes the strata which form a rocky eminence are placed in flat horizontal masses, one above another. The marginal figure may be supposed to represent a hill, the base of which is composed of granite, E; on which rests a stratum of gneiss or mica-slate, *D*; supporting one of sandstone, C; having above it another of Chalk with imbedded nodules of flint, B; crowned by clay, gravel, or any alluvial matter, A. Sometimes the strata composing rocks are inclined at angles more or less acute, varying from the horizontal to the vertical position. In some situations the strata take a waving course, rising with the undulating surface of the hills on one side, and declining on the other, in the manner represented in the annexed diagram.





Contorsions or sinuosities of strata, of a much more abrupt character, are also common in mountain ranges, indicating the peculiar operation of extraordinary force in their formation. "Contorsion requires that the rocks in which it is observable should have been in a yielding state, and that the particles were capable of a certain movement among each other, so that when force was applied no absolute fracture was occasioned. Sir James Hall has long since shown, that to produce contortion by lateral pressure, there must be resistance both above and beneath, the former at least being capable of yielding in a minor degree. He illustrated this fact by experiment, and showed that these conditions are necessary to the production of contorsions by lateral forces."* The experiment, which may be easily repeated, merely consisted in placing layers of various sorts of cloth upon a flat table, covering them with a loaded board, and applying lateral pressure, so as to raise the superincumbent weight to a certain extent, when the cloth became folded and contorted in a manner exactly analogous to the contortions of natural rocks.†

Contorted strata are especially observable on the flanks or skirts of mountain chains. The following figure exhibits a section of part of a mountain, in which a stratum of limestone, included between thinner strata of shales or slates, has, together with them, been acted on when in a yielding state, by forces which have caused deep and abrupt a-

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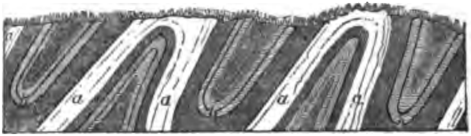
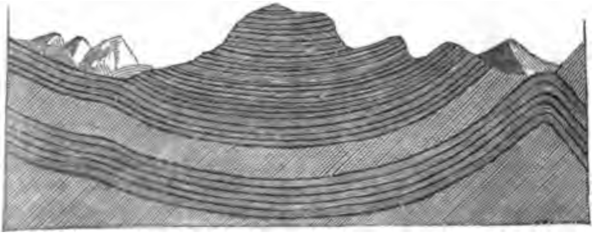
* De la Beche's Geological Researches, p. 127.

† Transactions of the Royal Society of Edinburgh, vol. vii. p. 85.



dulations of surface. The limestone stratum, *a*, *a*, *a*, *a*, is seen including in its sinuosities, the superior beds of shale, &c., marked *b*, *b*, *b*, and also inferior beds of the same nature. In the Alps, between Mount Righi and the Hospice of St. Gothard, a series of mixed strata of limestone, clayslates, shales, and sandstones, display such windings and convolutions, as might have been produced in the manner already described, by the combined operation of vertical and lateral forces.* Examples of the waving or zigzag direction of strata occur occasionally in our coal-mines: and at Anzin, near Valenciennes, a remarkable instance has been observed of this derangement of the coal strata, which are bent up and down, and covered by horizontal strata of chalk, marl, and clay, subsequently deposited.

The strata, instead of rising towards the summit of a hill, may be depressed in the centre, as if they had been deposited in a basin, or trough-shaped hollow.



The preceding figure represents a series of strata thus arranged, each stratum having the shape of a shallow inverted cone or dome, the edges of which may be traced all round the mountain. In the hill of St. Giles, near Liege, this conformation of the strata may be noticed: sixty-one beds of coal, alternating with rocky strata, form a mountain 3200 feet in height. In South Wales and other parts of this island, the coal strata are arranged in a similar manner.

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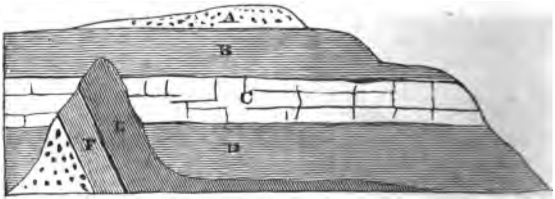
* See De La Beche's Geological Researches, p. 129.

When rocks belonging to different formations occur together, one resting on the other, that which is placed underneath is termed the *fundamental rock*, and that above it the *superincumbent*. The line where two rocks or formations come in contact is named either the *line of junction*, being viewed with reference to the position of the rocks, or the *line of separation*, as marking the distinction of their species. When the strata of a superimposed formation are parallel with those on which they rest, the stratification is said to be *conformable* as in the figure, p. 391, where the strata are all horizontal. Inclined strata may also be conformable, the same degree of inclination extending through all of them.

If, on the contrary, the superimposed strata are horizontal, while the subjacent strata are more or less inclined, they are relatively termed *unconformable strata*.



This mode of superposition is shown in the above diagram, representing a section of a part of a mountain composed of primary secondary, tertiary, and alluvial stratifications. The horizontal strata A, B, C, D, of sand, clay, shell limestone, and sandstone, conformable among themselves, are seen reposing unconformably on highly-inclined strata of slate and gneiss, E, F, which rest conformably on granite. The strata around Paris, consisting of alternate water and marine formations, are thus superimposed unconformably upon chalk, which forms a great basin, containing these various deposits, which also cover its edges in the less elevated parts, while in some places the chalk appears rising through the upper strata.

When series of strata are nearly horizontal, and extend through a considerable tract of country, intersected by deep valleys, the same strata will make their appearance at nearly the same level, in distant mountains. It is said, that in the vicinity of Pittsburgh, in Pennsylvania, a thick stratum of coal may be traced through many hills at the same elevation above the intermediate valleys. The coal may be worked by driving levels from the sides of the hills, forming open galleries, and thus obtained with little difficulty. Owing to the horizontal position of the coal, it forms the bed of a river, for several miles.

When curved strata of equal thickness at the top and sides lie unconformably on other strata, the former are said to be *saddle-shaped*; and when such overlying strata gradually become thinner from the base to the summit, thus wrapping round the sides of the subjacent or fundamental rock, they are termed *mantle-shaped strata*. Strata filling up a spheroidal cavity, are denominated *basin-shaped;* and, if the cavity be oblong, the superimposed strata are styled *trough-shaped*.

The upper part of a stratum or bed, which rising from under others makes its appearance at the surface, and where it consequently terminates, is designated by miners, the *outcrop*, or *basset-edge* of the stratum.

Strata are said to form *outlyers*, or *outlying rocks*, when they compose detached heights, once evidently continuous with extensive tracts of a similar geological structure. Isolated hills of this kind are found on the outskirts of mountain ranges or elevated plains, separated from hem by valleys of excavation.

Sometimes the continuity of a whole series of strata is interrupted, he beds having been apparently broken through, and shifted or heaved n one side, from their original position, constituting what is termed *fault*, or *slide*. These dislocations of strata are phenomena of an nalogous nature to the heaving of mineral veins, but they take place n a more extensive scale.*

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* For an account of the structure, arrangement, and composition of me-llic veins, see Treatise on *Metallurgy and Mining*, pp. 167—170.

A *dyke* is a wall of rock interrupting the continuity of strata, and filling up the fissures sometimes caused by faults or breaks. The ends of the strata on either side of the fissure are occasionally tilted or bent upwards, as if the dyke had been formed by the protrusion of matter from below. Dykes vary in thickness, from a few inches to many yards; and those which intersect coal-beds are composed of indurated clay, or more frequently of basalt.

The *dip*, or inclination of strata, that is, the point of the compass towards which they descend, is a circumstance deserving attention. It has been observed, that the dip is always at right angles to the range or direction of the strata; and that if the dip is given, the direction may be inferred, but a knowledge of the direction will not give us the dip. The amount of the dip of any strata is to be estimated by the angle which they form with the horizon; and this may be determined by means of the instrument called a clinometer, which is a compass with an attached quadrant. In this country the primitive and transition rocks often range or take the direction of north-east and south-west.

An *anticlinal axis* is that line from which the strata composing a hill dip in opposite directions. "The ridge of a house-top will convey an idea of this line, and the slope of the roof represent the dip of the strata."*

Some rocks, especially those of the trap kind, as porphyries and syenites, are said to be tabular. Dr. Macculloch terms the tables into which these rocks may be divided pseudo-strata.† "The tabular structure consists of parallel plates of rock, separated by regular seams. This structure has been often confounded with stratification; it appears to be the result of crystallization, and is closely allied to the columnar structure."‡

The only remaining description of rocks that can be considered as symmetrical, with regard to their external structure, are those which have been styled columnar. The most distinctly marked among the columnar rocks is basalt. The columns they exhibit are formed by the aggregation of prisms generally of a pentagonal figure, but some are liable to desquamation and superficial decomposition, when their angles become rounded, and their forms variously modified. Vast ranges of basaltic pillars occur in countries which have been the scenes of volcanic action, as the singular masses called the Giant's Causeway, on the northern coast of Ireland; and Fingal's Cave, in the Isle of Staffa, one of the Scottish Hebrides. The general appearance of extensive ranges of columnar rocks may be illustrated by the following diagram.

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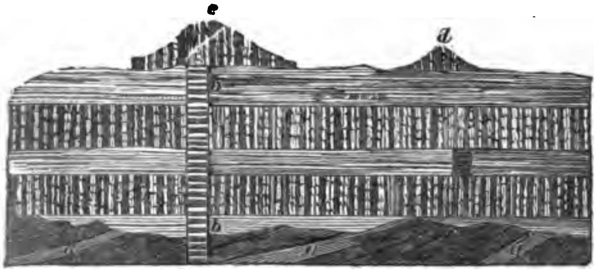
* De la Beche's Geolog. Man. Appendix.

† Geol. Classification of Rocks, p. 90.

‡ Bakewell's Introduction to Geology, p. 57.



Beds of stratified rocks, *a, a, a,* are cut through by a basaltic dyke of horizontal prisms, intersecting also ranges of vertical columns, and three large transverse dykes of amorphous basalt, *b, b,* above the highest of which are detached masses, *d* and *e,* of columnar basalt. This figure likewise exhibits the interior structure of prismatic rocks, and the manner in which the columns are divided by joints. The columns may not only be vertical or horizontal, as in the foregoing figure, but also inclined at any given angle, and sometimes the prisms are more or less curved, forming by their combinations rocks destitute of symmetrical arrangement.

Rocks which are neither stratified, tabular, nor columnar, can carcely be said to have any appropriate form; and we have therefore tyled them amorphous. They may vary in dimensions as much as in gure, and be of any size, even of mountainous bulk. Thus granite, reenstone, and some of the trap rocks, constitute vast pillars, blocks, and boulders, of every fantastic shape. Irregular masses imbedded i other rocks, are styled nodules. They are sometimes rounded, and not unfrequently flattened; "and in such cases, they pass into th form of non-persistent and extenuated strata. Nodules are often imbedded in stratified rocks; but they are also found in granite, as i the case with serpentine. The size of these masses varies from a foo to a mile or more."*

It is difficult to determine how far stratification extends among th primary rocks; and even granite sometimes exhibits traces of wh Dr. Macculloch calls pseudo strata.†

Classification and Arrangement of Rocks.

A cursory view of the masses forming the crust of the earth exhi so much confusion and indefinite variety of composition as mus pear to render nugatory all attempts at classification; and hence it at one time supposed, that the several formations were destitute of regularity in distribution and in individual characters. The first distinction that seems to have been made was that of the Ger miners, who arranged strata or rocks in two classes, namely, th containing metallic veins, and those which were non-metallifer Lehman, already mentioned (p. 295), made the much more impor division of formations into *primitive* and *secondary*, or those dest of organic remains, and those including such fossils. The celeb Werner modified and improved this division; adding two other cla the *transition* and the *local*, or as they were afterwards called, te rocks. Subsequent additions have been proposed of *alluvial* or su ficial deposits; and of *pyrogenous* strata, including the trap an canic rocks. These divisions have been generally adopted by m writers on systematic geology; though several have thought i subdivide the secondary and tertiary rocks into distinct grou formations.

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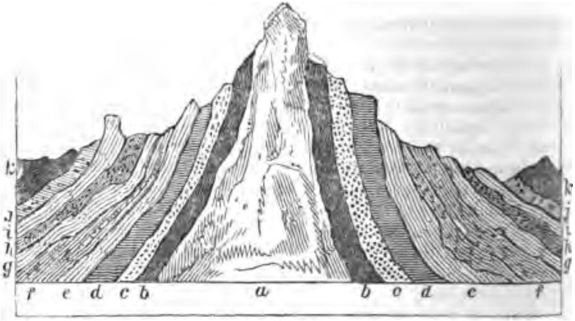
* Dr. Macculloch's Geol. Class. of Rocks, p. 113.

† See p. 327. On the subject of stratification in general, see Green Critical Examination of the First Principles of Geology, 1819, Essay I. Dr. Boase's Treatise on Primary Geology.

In assuming successions of strata to a greater or less extent superimposed around the terrestrial globe, we must be careful to distinguish what has been inferred from limited observation, confirmed, however, in a certain measure by uncontradicted experience, from the deductions derived from appearances of an unequivocal description. That granite, or rather granitic rocks constitute, as elsewhere stated, the basis or skeleton of the solid crust of the earth, is a conclusion formed from general observation that these rocks where they most extensively occur seem to rise from under other rocks which are known to occupy relatively low situations, or they form nearly vertical masses so included between other rocks as to indicate that the granite passes beneath those rocks. Since, however, the extent of surface of granitic rocks, naturally or artificially exposed, is but inconsiderable compared with that of the earth's surface, the notion that granite composes the inner shell or lining of the earth's crust is at best but a probable conjecture. Granite, then, can only be *supposed* to be an universal formation; and the extent of many of those above it must at present be utterly uncertain. But with respect to some of the superior strata, we know with certainty that they are *not* universal formations, and that some cover only limited areas. Coal appears to consist of circumscribed beds formed in basins or concavities of older strata; the clays of the London basin, and the various deposits of the Paris basin, also compose circumscribed beds. Chalk, if it deserves the character of a general formation (as it is certainly a very extensive one), is not now universal, having been removed apparently from some parts of the surface of this country, as the Weald of Sussex, by the violent action of water. It is only by the gradual accumulation of facts that the boundaries of real knowledge can be extended. From their situation the more superficial rocks may be supposed to have been the most thoroughly investigated, and since it has been ascertained that they include organic remains extremely singular and curious, they have attracted particular attention: as the progress of research proceeds, however, it may be expected that the primordial or inferior rocks will also be more closely examined, and that thus various disputed points with regard to them will be satisfactorily decided.

The manner in which the several formations and rocks are arranged so as to form mountain masses may be illustrated by the following representation of a section of the Brocken Mountain, in the Hartz Forest, in Germany.



The perpendicular mass in the centre, *a*, is granite, which may be supposed to extend laterally beneath the other rocks; *b*, *b*, is clay-slate, immediately enveloping the granite; *c*, *c*, is transition limestone; *d*, *d*, greywacke slate; *e*, *e*, old red sandstone; *f*, *f*, mountain limestone, *g*, *g*, gypsum; *h*, *h*, variegated sandstone; *i*, *i*, second or newer gypsum; *j*, *j*, second limestone; *k*, *k*, alluvial deposits. It may be proper to observe, that this section exhibits only the arrangement and successive declination of the rocks that form the Brocken, and not their respective forms and dimensions; and that in other mountains some of these strata may be replaced by others, or be entirely wanting.

SYNOPTICAL ARRANGEMENT OF GROUPS, FORMATIONS, AND ROCKS.*

I. *Primordial or Non-fossiliferous Rocks.*

A. Unstratified Rocks. Granite, Syenite. Greenstone. Serpentine. Schorl Rock, &c. B. Stratified Rocks. Gneiss. Mica Slate. Clay Slate. Quartz Rock. Hornblende Slate, &c.	Grampian Hills, in Scotland; Cornwall; Dofrine Hills, Norway; Ural Mountains, Russia; Erzegebirge, in Saxony; Riesengebirge, in Silesia; Pyrenean Mountains; Eastern Alps, from St. Gothard to the plains of Hungary; Alleghany Mountains, United States, N. A.; Andes, S. A.

II. *Submedial Rocks.*

(*Greywacke Group of Lyell and De la Beche. Transition Rocks of other Geologists.*)

Sandstone conglomerate, slate, &c. Shropshire.

Calcareous flags, sandstone, and schist. Radnorshire.

Shell limestone, and micaceous sandstone, &c. May Hill, Gloucestershire.

Coralline limestone, and argillaceous shale. Wenlock, Shropshire; Dudley, Worcestershire.

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* This synoptical table is chiefly founded on "Table II. Showing the Order of Superposition, or Chronological Succession of the principal Sedimentary Deposits or Groups of Strata in Europe."—Appendix to Lyell's *Prin. of Geology*, vol. iv., with Additions and Modifications, derived from De la Beche's *Geological Manual;* Brongniart *Tableau des Terrains qui composent l'Ecorce du Globe;* D'Aubuisson *Traité de Geognosie*, 2nde edit., continuée par Amédée Burat., tom. i. 1834; Mantell's *Geology of the South-east of England*, chap. ii.; and *Outlines of the Geology of England and Wales*, by Conybeare and Phillips, pt. i. Introduction.

Submedial Rocks *continued.*

Argillaceous limestone, and sandy shale. Shropshire, Herefordshire.

> "The grauwacke group occurs in Norway, Sweden, and Russia. It forms a portion of southern Scotland, whence it ranges with breaks, as far as regards the surface, formed by newer deposits of the sea, down western England and Wales, into Normandy and Brittany. It appears abundantly in Ireland. A large mass of it is exposed in the district constituting the Ardennes, the Eifel, and the Taunus. Another mass forms a large portion of the Hartz mountains, while smaller patches emerge in other parts of Germany, on the north of Magdeburg and other places."—De la Beche's *Geol. Man.*, p. 430. The terms *greywacke* or *transition* are applied as epithets to distinguish the sandstones, slates, and limestones of this group from those which occur in other groups.

III. *Medial Rocks.*[*]

Carboniferous Group.

a. Old red sandstone. Shropshire, Herefordshire, and Brecknockshire; Dumfriesshire, Forfarshire.

b. Mountain limestone. Mendip Hills, Somersetshire; Derbyshire, Yorkshire, Northumberland, Durham.

c. Coal measures, including sandstones, conglomerates, clay with ironstone, shales, and limestones. Northumberland, Durham, Yorkshire, Lancashire, Staffordshire, South Wales; District of Liege, Westphalia, Silesia, Bohemia; United States, N. A.; Valley of the Mississippi; New South Wales; Van Diemen's Land.

IV. *Supermedial Rocks.*[†]

1. Penean, or Red Sandstone.
2. Keupric, or Poecilian.
3. Liasic.
4. Oolitic, or Freestone.
5. Wealden.
6. Cretaceous.

Groups.

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[*] See the following note.

[†] The rocks belonging to this and the preceding order (the Medial and Supermedial Rocks, or those from the Old Red Sandstone to the Chalk, inclusive) constitute the Secondary Formations of the Wernerians.

Penoan Group.

a. New red sandstone [*Rothliegendes*, Germ.] [*Grès Rouge*, Fr.] Near Exeter, Devon; Valleys of the Vosges, in France; Thuringia, Saxony, Silesia; New Spain, N. A.; Venezuela, New Grenada, Peru, S. A.

b. Magnesian limestone [*Zechstein*, Germ.] Northumberland, Durham, Yorkshire, Nottinghamshire, Derbyshire; Dep. of Calvados, in France; Westphalia.

Keupric Group.

a. Variegated sandstone [*Bunter Sandstein*, Germ.] [*Grès Bigarré*, Fr.] Yorkshire, Nottinghamshire; Vosges Mountains, Cevennes, mountains of Aveyron, France; Swabia, north and west of the mountains of the Black Forest, Germany.

b. Shell limestone [*Muschelkalk*, Germ.] Around the Vosges, France; Hartz (Blankenbourg), Hesse, Hanover, Wirtemberg, Germany.

c. Red or variegated marls [*Keuper*, Germ.] [*Marnes Irisées*, Fr.] Various parts of the north of France and Germany.

Liasic Group.

a. Alum slate [*Ampelite Alumineux*, Fr.] Whitby, Yorkshire.

b. Dark blue marl, with beds of rubbly limestone—sandy marlstone. Metz, in France; mountains of Jura, Tyrol, Bavaria, Wirtemberg, Westphalia.

c. Blue, white, and yellow earthy limestone, interstratified with clay, often slaty and bituminous [*Quadersandstein*, Germ.] Lyme, Dorsetshire, Somersetshire; Sutherland, Hebrides, N. B.; North of Ireland; Luxembourg; Aalen, Valley of the Neckar; Col de Balme, Alps.

Oolitic Group.

a. Inferior oolite. Wilts, Cotswold Hills, Gloucestershire; Dundry Hill, near Bristol; Coal-field of Brora, Sutherlandshire, N. B.; Normandy; central part of mountains of Jura.

Oolitic Group *continued.*

b. Great oolite, Bath stone, Caen stone. Kettering, Northamptonshire; Burford, Oxfordshire; Mauriac, Aveyron, in France; Central Jura.

c. Bradford clay [*Marne argilleuse Jurassique*, Fr.] Bradford, Wilts.

d. Forest marble. Whichwood Forest, Oxfordshire; Frome, Somerset; Eichstadt, Franconia; Solenhofen, Germany.

e. Cornbrash. Malmesbury, Chippenham, Wraxall, Wilts.

Bradford Clay and Cornbrash ought, perhaps, to be regarded as local formations, and to be included under that of Forest Marble or Lithographic Slate; with which, where they occur, they are associated. Burat, indeed, reckons Bradford Clay, Forest Marble, and Cornbrash, as distinct but consecutive members of the Oolitic Formation; and Lyell distinguishes the Cornbrash from the Forest Marble.

f. Oxford Clay—dark, blue, tenacious clay; bituminous shale; sandy limestone (Kelloway Rock). New Malton, Yorkshire, Lincolnshire, Cambridgeshire, Somersetshire, Dorsetshire; abundant near Oxford; Dives, Mamers, and Marquise, in the Boulonois, in France.

g. Coral Rag [*Calcaire Corallique*, Fr.]—calcareous, shelly, oolitic freestone; coarse limestone, full of corals; yellow sand; siliceo-calcareous grits. Headington, near Oxford; Faringdon, Berks; Wiltshire, Somersetshire; Normandy, South of Germany.

h. Kimmeridge Clay [*Marne argilleuse Havrienne*, Fr.]. Near Kimmeridge, on the coast of Dorsetshire; Wiltshire, Somersetshire; Cape la Hève, Havre, and Honfleur, Normandy.

i. Portland Stone—coarse, shelly limestone, fine-grained white limestone, compact limestone—all oolitic; beds of chert. Isle of Portland; Tisbury, Wilts; Aylesbury, Bucks; Grisnez, in the Boulonois, and Dep. of Upper Saone, France.

Wealden Group.

a. Purbeck Stone—various kinds of limestones, alternating with marls. Isle of Purbeck, Dorsetshire.

b. Ashburnham Stone—bluish-grey limestone, alternating with blue clay, and sandstone shale. Archers' Wood, near Battel; and Ashburnham, Sussex.

Wealden Group *continued.*

- *c.* Hastings Sands and Clays—fawn-coloured and white sand, and friable sandstone, with clays and calcareous grits. Sussex (including the strata of Tilgate Forest), western parts of Kent, Isle of Wight.
- *d.* Weald Clay—slaty clay, and limestone, with beds of ironstone, and Sussex marble. Weald of Sussex, Isle of Wight; Bas Boulonois, and Beauvais, France.

Cretaceous Group.

- *a.* Shanklin Sand, Lower Green Sand [*Glauconie Sableuse*, Fr.]—green, grey, white, and ferruginous sand, with clay, chert, and siliceous limestone. South of Kent, western part of Sussex; Le Blanc (Indre), Réthel (Ardennes), France.
- *b.* Gault, or Folkstone Marl—blue clay, with veins of red ochre. Alice-holt Forest, Hants; near Arundel, Sussex; Folkstone, Kent; Cambridge.
- *c.* Upper Greensand, or Firestone [*Glauconie crayeuse*, Fr.]—marly stone, and sand with green particles; layers of calcareous sandstone. Southbourn, Steyning, Bignor, Sussex; Reigate, Surrey; Valenciennes, Havre, France.
- *d.* Chalk, without Flints. Lower division of the South Downs.
- *e.* Chalk, with Flints, or Upper Chalk. Upper portion of the South Downs.

  The Chalk Formations, *d* and *e*, are very extensive in France, and other parts of the continent of Europe.

- *f.* Maestricht Limestone—soft, yellowish-white limestone, with siliceous masses, resembling chalk. St. Peter's Mount, Maestricht; Ciply, near Mons.

V. *Superior Rocks.*

(*Supracretaceous, Tertiary, or Newest Floetz Rocks of different Authors.*)

Lower Formations.

- In England (London Basin).
  - *a.* Plastic Clay.
  - *b.* London Clay.
  - *c.* Bagshot Sand.
- In France (Paris Basin).
  - *a.* Plastic Clay.
  - *b.* *Calcaire Grossier.*

Upper Formations.

A. Calcareo-siliceous strata, gypsum, and marls, sand and sandstone, millstone grit, and marls. Superior strata of Paris Basin.

B. Marine deposits of sand, forming the Fahluns of Touraine, and of the Lower Loire, France.

C. Subapennine marl, subapennine yellow sand; English crag; and other deposits containing marine fossils. Perpignan, Nice; Norfolk, and Suffolk.

D. *Molasse* and *Nagelfluhe*—accumulations of rolled pebbles and sands, composed of Alpine detritus. Switzerland.

E. Limestone, sands, clays, sandstones, conglomerates, marls, with gypsum; containing marine fossils. Sicily, Ischia.

VI. *Alluvial Deposits.*

A. Sand and Gravel—auriferous sands, cascalhao.

B. Detritus of various kinds—calcareous sandstone, with broken shells; osseous breccia.

C. Recent Calcareous Formations—coral reefs and islands, tufa, travertin.

D. Peat.

VII. *Volcanic Strata.*

Ancient—
  Basalt, trachyte, greenstone, &c.
Recent—
  Lava, ashes, moya, &c.

ORYCTOLOGY.

The term Oryctology[*] has been employed to denote the Natural History of Minerals and Fossils, with especial reference to the situations they are found to occupy within or upon the crust of the earth. Mineral and fossil are words of analogous signification, implying bodies that have been obtained by mining or excavation; but the former is now usually appropriated to those bodies which are mere chemical compounds, exhibiting no traces of organization; and the latter to such as retain in any degree the form and appearance of animal and vegetable substances, however changed or modified as to their composition. These bodies might be generally designated metamorphosed organic remains, were they not sometimes presented to us by nature absolutely unaltered, as in the very remarkable instance of the fossil elephant, found embalmed in ice, in Siberia, in the beginning of the present century.

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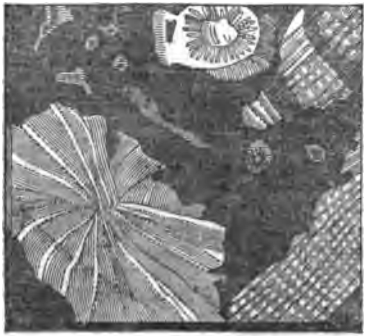
[*] From the Greek 'Ορυκτός, *fossil*, and Λογος, a *discourse*.

From the structure and composition of animal and vegetable substances, however, it necessarily follows, that but very few comparatively can occur in such a state of complete preservation. Trees are sometimes found buried in bogs and mosses, standing erect, with their roots and branches very little altered. The more dense and compact parts of organized beings are most frequently preserved, while the softer substances which entered into their composition have been destroyed or removed. Hence whole skeletons, or detached bones, and shells, either entire or broken, are among the most common fossilized organic remains. They occur, however, under variously modified conditions: some having undergone little change of substance, as those masses of shells and corals, which, being conglutinated by carbonate of lime, form blocks or beds of variegated marble.



The preceding figure represents the surface of a slab of Kilkenny Marble, inlaid with shells and coralloids, which have a very pleasing effect; and many of which are so perfect, that their forms may be traced, and their species distinguished.

The Sussex or Petworth Marble is another kind of shell limestone, which affords beautifully-veined sections, and has been used for ornamental purposes. It is found in layers varying from a few inches to a foot or more in thickness, in the Weald clay, in the south-eastern part of England. "This limestone is of various shades of bluish-grey, mottled with green and ochraceous yellow, and is composed of the remains of fresh-water univalves, formed by a calcareous cement into a beautiful compact marble. It bears a high polish, and is elegantly marked by the sections of the shells which it contains: their constituent substance is a white crystallized carbonate of lime, and their cavities are commonly filled with the same substance, presenting a striking contrast to the dark ground of the marble. In other varieties, the substance of the shells is black, and their sections appear on the surface in the form of numerous lines and spiral figures. Occasionally a few bivalves (*cyclas*) occur, and the remains of the minute crustaceous coverings of the *cypris faba* very constantly."* This limestone is durable; "yet from long exposure in damp situations, it undergoes decomposition, and the petrified testacea may then be extricated almost entire."†

The mountain limestone—called by Mr. Bakewell, "upper transition limestone"—"is one of the most important calcareous rocks in England and Wales, both from its extent, the thickness and number of its beds, the quantity and variety of its organic remains, and its richness in metallic ores, particularly of lead. In Derbyshire, where the different beds of limestone have been pierced through by the miners, the average thickness of the three uppermost is about 160 yards: the beds are separated by beds of trap or basalt, resembling ancient lavas. The lowest limestone has not been pierced through."

"The prevailing characteristic organic fossils are encrinites and madrepores. The upper beds of mountain limestone, in Derbyshire, appear to be almost entirely composed of encrinites."[*] At the British Museum there is a table consisting of a polished slab of entrochal or encrinital marble, from Bakewell, in Derbyshire; a portion of which is exhibited in the following figure.

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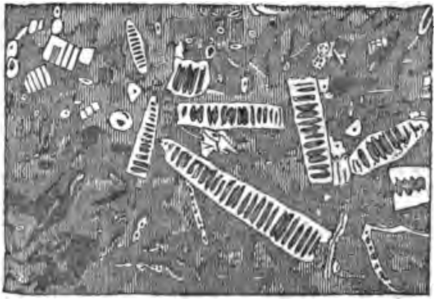
* Mantell's Geology of the South-east of England, p. 184.

† Idem, p. 186.



This table is of a light grey colour, variegated with white; but the mountain limestone has occasionally a black, and sometimes a reddish-brown ground, or is veined or clouded.

A bed of black marble, with madrepores, is found in Westmorland, and in the lower part of the mountain limestone in North Wales and Shropshire, and likewise in Devonshire; but it occurs more rarely in Derbyshire. The black tint of this marble is owing to the presence of bitumen: it otherwise generally is composed of nearly pure carbonate of lime, except some beds, which consist partly of carbonate of magnesia.

Sometimes the organic remains are found to have undergone considerable modification as to their composition, while their forms exist unaltered. Thus vegetable bodies are changed into ochraceous earth or tuff, like the umber found in the environs of Cologne. Wood impregnated with silex is not unfrequently met with in various parts of the world; but the finest specimens are said to be obtained from the vicinity of Schemnitz and at Telkobanya, in Hungary. It also occurs in this country, in the diluvian detritus, in the green sand of the cretaceous group, and in the Portland stone. The texture of wood may be traced in some siliceous minerals, as jasper, agate, calcedony, opal, and pitchstone, betraying their ultimate origin. Argillaceous earth may cause the mineralization of wood; and different parts of vegetables are often imbedded in the rocks composed of this earth. Iron in the state of sulphuret, or in that of carbonate, may pervade the substance of vegetable fossils. "Innumerable seeds, seed-vessels, &c., have been found, by Mr. Crow and others, in the blue clay of Sheppey, in the state of pyrites. Most of these belong to plants unknown to our botanists; the existing plants to which the others seem to approximate are some of those of the warmer climates."* Wood is occasionally impregnated with pyritical or carbonated copper, the latter forming very beautiful fossils, the finest specimens of which (consisting of charred wood, marked with the most vivid blue and green tints, with patches of the carbonate in the state of malachite) are obtained from the copper-mines of Siberia.† Volkmann and other authors have mentioned fossil wood impregnated with silver; but its occurrence is somewhat questionable.‡ Specimens of wood thoroughly impregnated with galena (sulphuret of lead) have been found in Derbyshire.§

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[*] Bakewell's Introduction to Geology, p. 131.

As might be expected from their original composition, vegetable fossils are often found to have undergone changes which have reduced them nearly to the state of carbonaceous or bituminous minerals. Schookius relates, that masses of bitumen are frequently found among peat; and sometimes resembling, in size and figure, walnuts, eggs, and pine-nuts.‖ Wood is also found in the state of jet, lignite, and Bovey coal. This lastmentioned fossil, which occurs in several successive strata at Bovey, near Chudleigh, in Devonshire, extending for some miles, has been worked for more than a century, being used for fuel in burning lime and for other purposes.

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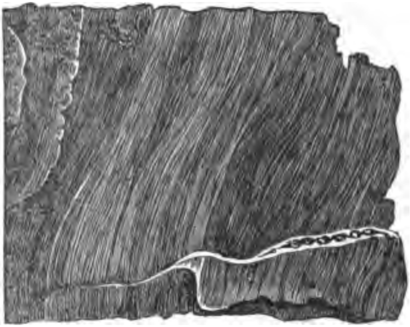
* Parkinson's Outlines of Oryctology: an Introduction to the Study of Organic Remains. 2d edit. 1833. p. 27.

† See Parkinson's Organic Remains of a Former World. 2d edit. 1833. vol. i. pp. 388, 389.

‡ Idem, p. 390.

§ See Martin's Outlines of an Attempt to establish a Knowledge of Extraneous Fossils on Scientific Principles, p. 150.

‖ Parkinson's Organic Remains, vol. i. p. 208.



The preceding figure represents a fragment of Bovey coal. "This variety is evidently a dicotyledonous or gymnospermous phanerogamic plant, for it presents all the external characters of stems belonging to that class."* Here the traces of the woody tissue are very distinct, and the structure but little altered. This fossil is only found in the superior strata; but the remains of vegetables are likewise abundant, as might be anticipated, in the coal formation, where however they occur, in general, more entirely metamorphosed. The annexed figure is a representation of a strobilus or cone of a pine (*pinus antiqua*), preserved at the British Museum, which has been completely carbonized.

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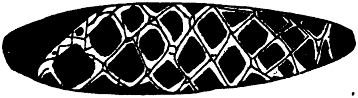
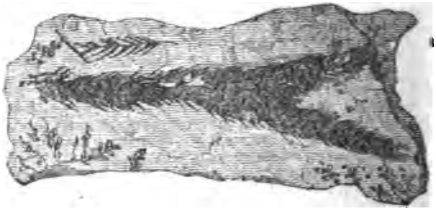
* The Internal Structure of Fossil Vegetables found in the Carboniferous and Oolitic Deposits of Great Britain, described and illustrated. By Henry T. M. Witham, of Lartington, F.G.S., F.R.S.E., &c. Edinb. 1833. 4to. p. 50. To the finely-executed plates which accompany this work, we are indebted for the figure in the text, and for those of some of the vegetable fossils represented in the following pages. Mr. Witham has contributed much, by his skilfully-conducted researches, towards obtaining an accurate knowledge of the internal structure of fossilized stems of plants; and by an improved method of cutting and polishing those bodies, so as to adapt them for microscopical examination, he has been enabled to elucidate their intimate organization, and thus to afford the most essential means for ascertaining their relative affinities with the genera and species of existing vegetables: a circumstance obviously of the highest importance with regard to bodies of which the more characteristic portions, the foliage and organs of fructification, have very rarely escaped destruction.



The transformation in some cases is so complete, that though the forms and even the colours may be preserved, all the elements of an organized being have been removed by the mysterious operations of nature. Such bodies are mere casts of the originals, and it not unfrequently happens that branches of trees, or some other parts of vegetables, or those of animals, having been inclosed in stony matter, the original substance has disappeared, but on dividing the lapidescent table, the impression of the organized bodies will be found on one layer, and casts in relief on the other. In general the inferior surface of leaves is displayed in relief, and the superior is indented. The small veins and hairs that mark these surfaces are occasionally preserved in perfection, apparently, while not a particle of animal or vegetable matter remains in the stone, the whole having been volatilized. The following figure exhibits a mould or impression of a branch of a tree, with leaves resembling the fir or yew, on shale, or limestone, from the British Museum, and on the margin of the mass are traces of some other vegetable, probably a fern.



Among the fossilized remains of vegetable foliage, the most abundant, especially in the shales and argillaceous schists above the coal, are those which belonged to different kinds of ferns. It is, however, very difficult to identify them with living species. Dr. Woodward states, that out of one hundred and thirty-eight specimens which he submitted to the examination of four eminent botanists, they were able to point out only eleven which bore a decided resemblance to those now existing, and twenty-three were totally unlike any English plant.* Mr. Parkinson laid some fossilized ferns, of which he has given figures, before Sir James E. Smith, who observed that "these fossil remains of vegetables are a sort of botanical riddles; and with respect to those which appear to be ferns, the difficulty of determining to what species the several representations may be referred, is augmented by there being so many things which they may be, and so many things which they nearly resemble, without being the same." He spoke doubtfully of almost all of them, but conjectured that they were all foreign, and productions of a warm climate.† The annexed figure represents the impression of a branch of fern, and others will be given in a subsequent page.

Mr. Parkinson questions the existence of *antholithes*, or fossil flowers, or at least asserts that it is merely conjectural. He says, "The tender and almost succulent substance of the petals, stamina, and pistilla, will furnish very little reason for supposing that they should resist a destructive resolution, sufficiently long to allow them to pass through those chemical changes, by which such duration would be given to their original forms, as would secure their passing unchanged in their figure from the vegetable to the mineral kingdom."

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* Dr. Woodward's Natural History of English and Foreign Fossils, 1729, vol. i.; Catalogue of English Fossils, part ii. p. 9.

† Parkinson's Organic Remains, vol. i. pp. 416, 417.

The *existence* of impressions of flowers in the fossil state, appears from specimens preserved in the British Museum; and floral forms may thus be exhibited, so that their resemblance to those of recent plants may sometimes be traced, as in the marginal figure, which represents a mould or impression of a radiated or stellated blossom, apparently of a syngenesious plant, like the marigold or china aster.

It is certain that "the earlier writers on this science too frequently admitted resemblances, when the connexion between the supposed model and the archetype were too equivocal to authorize them. Thus Mylius imagined that he traced the flower of the mouse-ear on a flint, and the rose of Jericho on a schist, from Manebach, both of which M. Walch believes were in reality, merely impressions of trochites."* Fanciful as the analogies undoubtedly were by which some authors have been led to describe certain fossils as antholithes, there can be no doubt but flowers as well as leaves, have sometimes been imbedded in rocks in such a manner that their forms have been more or less preserved, furnishing casts or impressions. The annexed figure exhibits a beautiful impression on sandstone of a branch of a tree, with long lanceolate leaves and blossoms, or rudiments of blossoms, preserved

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* Parkinson's Organic Remains, vol. i. p. 437.

in the same national repository with that from which the last figure was taken.

In the case of shells, corals, or other bodies included in limestone and sandstone rocks, the whole organic substance may be dissolved and carried away, leaving a cavity in the rock bearing the impression of the foreign body, and in this cavity is a mould or cast of the interior. Thus the *screwstones*, as they are called, have been cast or moulded in the cavities of crinoidal columns. "The most extreme case of mineralization or petrifaction is produced by a process in addition to that just described, when the cavity left by the removal of the shell or coral is again filled up by crystals of calcareous spar, deposited by water filtrating through the stone. Sometimes only a few crystals connect the inner mould or cast to the exterior impression, but generally the whole cavity is filled by the spar, which thus represents truly the shape of the original body, but displays no trace whatever of its internal texture."[*]

With respect to the changes that organized bodies undergo, they must be influenced considerably by the nature of the containing rock. "In the green sand almost all the shells are silicified; in the oolitic rocks many are changed to calcareous spar, in the clays very slight changes have happened to any of the organic remains. On the other hand, the original nature of the organic substance has very much influenced its mode of conservation. Echinital and crinoidal remains are almost invariably converted to a peculiar kind of opaque calcareous spar, in whatever strata they occur: gryphææ and astrææ retain their laminæ, inocerami and belemnites their fibres." As to vertebrated animals, "their soft portions have perished, but their teeth, bones, and scales remain, either connected or separated in consequence of the decay of the ligaments, cartilages, &c. The hardening ingredient of bones is principally phosphate of lime, that of teeth is a mixture of phosphate and carbonate of lime. It is generally the fact that their gelatinous or membranous portion has been diminished, and their earthy admixture increased, by the subterranean chemistry to which they have been subjected, and, in consequence, their specific gravity is much augmented."[†]

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[*] Encyclopæd. Metropol.—Treatise on Geology, vol. iv. p. 548.

[†] Idem.

GEOLOGICAL ARRANGEMENT OF MINERALS AND FOSSILS.

There are two modes of formation to which the origin of the rocks composing the crust of the earth might be ascribed. The first consists in the more or less rapid consolidation of masses which had been previously in a dissolved state; and the second in the gradual deposition of solid matter from a fluid with which it had been mechanically or chemically combined. Vast fields of ice, and beds of lava, are occasionally or periodically formed at present, by the more sudden process of solidification; and layers of silt and sand, and beds of travertin limestone, are produced by the slower method of precipitation. The inferior unstratified, as well as the trap rocks, are usually considered as being, like those of volcanic origin, the results of igneous fusion and congelation. But all the stratified rocks are regarded as aqueous deposits, and these, which are by far the most numerous, must have owed their existence to the protracted operations of nature.

The stratified rocks, from the greywacke series to the tertiary and alluvial formations, include a multitude of distinct deposits, most of which inclose organic remains derived from successive races of animals and vegetables, comparatively few of which, except in the upper formations, seem to have any living congeners, but on the contrary, many of these relics present us with the forms of strange beings that once peopled the earth, and which have ceased to exist for countless ages past. Rocks arranged in strata one above another may, by their peculiarities of structure and contents, afford the means for ascertaining their relative age or rather order of formation.

" Geognostic epochs," says Brongniart, " are very different from chronological epochs: the latter are determined by the succession of time, but not so the former, which are founded on the grand phenomena or catastrophes that limit a geognostic period. By this term we designate the whole time during which the same geognostic phenomena have taken place on the surface of the earth. These periods may amount to numerous ages, or to only a few years: thus the space of time during which the granite displayed itself over all parts of the surface of the globe, accompanied by the minerals which it contains, forms a remarkable geognostic period. That in the course of which the Trilobites existed, with their contemporary organized beings, whilst the argillaceous schists, and the carboniferous and bituminous limestones were deposited, was another geognostic period, of which the average duration of the life of a trilobite, and the number of the generations, if it were possible to discover them, might loosely indicate the duration. We have another remarkable example of a geognostic period in the state of repose which seems to have prevailed in the crust of the earth, since the existing continents have received their forms and limits, the sea assumed its level, and the atmosphere its temperature; since the animals and vegetables that inhabit the sea, or live on the surface of the earth, have varied but little from what they are at present; this state of repose, established by all observations, all historical traditions, constitutes the last geognostic period, the commencement of which must be dated at least four thousand years ago, and which may extend for a long series of ages to come.

"As we are ignorant whether the arrangement of the different groups is similar over the whole globe, it is impossible to determine whether the geognostic periods have been of equal extent, and also contemporaneous over the surface of the earth. For instance, whether since the Ammonites and the Belemnites have ceased to live, and the chalk to appear in Europe, in order to be succeeded by the Cerites and the tertiary deposits, the first mentioned cephalopodous molluscs have not continued to exist, and the chalk to be deposited in India and in America."*

From the preceding observations, it must be concluded that though certain European groups or formations may be characterized by the presence of particular fossils, the same formations may occur in other quarters of the world unaccompanied by such fossils, or the fossils may be found in rocks differing in mineralogical composition from those in which they appear in Europe. It is, however, a point of importance to be enabled to discriminate, by reference to their contents, the rocks of a single continent, or even those of any one country; and thus far, at least, it may be admitted that geognostic oryctology has advanced.

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* Tableau des Terrains qui composent l'Ecorce du Globe, Introd. pp. 8, 9.

Primordial or Inferior Rocks.

These rocks are negatively characterized by the absence of any organic remains, or conglomerated fragments of transported matter: whence it may be inferred that, however they might have been produced, they underwent the process of consolidation in a short space of time; unlike the sedimentary rocks, which were formed by gradual and successive depositions. It is also supposed, that since there are no relics of animals or vegetables in the stratified inferior rocks, their formation must have preceded the existence of organized beings on the surface of the earth. The inferior rocks (including in that appellation the greywacke formations, from which some of the lower rocks can scarcely be distinguished) are the grand repositories of mineral bodies. Among them are found the metals and metallic ores, the gems, and other rare and curious mineral compounds. These, indeed, occasionally occur in the ascending strata; but it will in general be evident that such minerals have been detached from their original situations, and dispersed by some convulsion of nature; as is the case with diamonds which are found enveloped in the cascalhao, a comparatively recent deposit in Brasil; with the gold dust obtained from fluviatile sands, and the stream-tin of Cornwall.

Some metals, as tin, tungsten, and molybdena, are almost exclusively the produce of the primordial rocks, or are immediately derived from them; and gold, silver, lead, copper, iron, cobalt, zinc, manganese, arsenic, and mercury, are abundantly disseminated through rocks of this class, in veins, beds, strings, or detached nodules; and many primitive districts are characterized by the metalliferous deposits they contain. "Nothing can be more beautiful than the *drusy cavities* met with in primitive mountains, whose walls are lined with pure and variously tinted and crystallized topaz, beryl, rock crystal, fluor spar, and calcareous spar; the gneiss, granite, and mica slate, with their *imbedded* crystals and grains of sapphire, chrysolite, and garnet; and the *veins* in granite, clayslate, and other primitive rocks, with their emeralds, axinites, and spinel rubies, afford to the mineralogist highly interesting combinations."*

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* Encyclopædia of Geography, pt. ii. book ii. p. 220.

Observations on the deposition of silica from the water of hot springs, together with the supposed impossibility of forming some mineral compounds by fire, induced the geologists of the school of Werner to ascribe the production of granitic rocks to water. But the discoveries of Sir James Hall and Mr. Gregory Watt, relative to the effect of gradual cooling on carbonate of lime and other bodies fused by heat, causing them to assume a crystalline structure, invalidated the arguments derived from the second consideration; and subsequent researches afford abundant evidence of the igneous origin of granitic rocks and their included minerals. Mitscherlich found that the slags from iron smelting-furnaces are often crystallized, have the form of augite, and agree with it in chemical composition. He, also, by exposing to intense heat the substances of which certain minerals consist obtained crystals of those minerals: thus producing artificially, amphibole, mica, and hyacinth. Berthier, likewise, formed silicates of manganese, as well as of iron, in his furnaces, and obtained them regularly crystallized.* Admitting, then, that granitic rocks and those with which they are more directly associated were formed by consolidation, after having been fused by heat, it must be manifest that if shells or other parts of living beings had entered into their composition, no traces of them would have remained, since as to structure, at least, they must have undergone utter destruction. The primordial rocks, therefore, may be regarded as being distinguished by the absence of organic remains, and being the chief repositories of minerals.

Submedial Rocks.

With respect to these rocks and the higher strata, our space will admit of only a few notices of the characteristic fossils of the several rocks or formations, with descriptions of some of the more curious and important.

The submedial or transition rocks are not unfrequently so intermixed with the stratified primordial rocks, that it is difficult to discover the distinction between them.* Viewed on the large scale, they consist of "a stratified mass of arenaceous and slaty rocks, intermingled with patches of limestone, which are often continuous for considerable distances. The arenaceous and slate beds, considered generally, bear evident marks of mechanical origin, but that of the included limestones may be more questionable."†

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* See Johnston on Chemistry, in Rep. of Brit. Assoc. 1832. p. 486; Cuvier Discours sur les Progrès récens de la Chimie, prononcé en Mai, 1826, dans une Seance des Quatre Académies; and Annales des Mines.

It is in the calcareous rocks of this class chiefly that organic remains are found; for the greywacke sandstones appear to contain none, and the transition slates relatively few. The vegetable fossils found in these rocks are seldom in such a state as to afford traces of their analogies with those of living plants. So far as can be determined from those which have been made out, it appears that the same kind of vegetation probably prevailed during the period in which these formations took place, as during the depositions of the carboniferous rocks.

As to the animal fossils, they are generally derived from the lower orders of beings, consisting principally of zoophytes, radiated animals, conchifers, molluscs, and crustaceous animals. A few ichthyolites have been found, indicating the existence of at least one genus, and two or three species of fishes. These rocks contain a mixture of *genera* of animals inhabiting the seas and oceans of the present day, and of others which are now not known; but the *species* are all become extinct.

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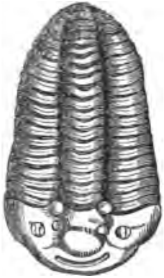
* This difficulty is fully admitted by one of the latest writers on systematic geognosy. "Some of the rocks constituting the primitive group are continued, and still more developed in the transition group; as the argillaceous schists and calcareous rocks; and others, as the quartz and the greywacke, are intimately connected with the primitive quartz and schists; so that it might be supposed, that from the lowest granites to the upper transition rocks there was only one grand period."—*Traité de Geognosie; mis en Rapport avec l'Introd., pub. en* 1828, *par M. D'Aubuisson de Voisins. Par Amedée Burat.* 1834. tom. i. p. 209. Hence M. Burat proposes a division of the transition rocks into two parts or classes. Mr. De la Beche remarks, that "towards the lower part of the grauwacke group its fossiliferous character disappears, and the presence of crystalline rocks, apparently of contemporaneous origin, becomes more common. This change varies much in different countries; but in general the slaty rocks gradually prevail, presenting a very great thickness of argillaceous schists. We seem to have arrived, in the descending order, at a state of the world when there was a combination of those causes which have produced fossiliferous and non-fossiliferous rocks."—*Geol. Man.*, p. 422.

† De la Beche's Geol. Man., p. 414.



Among the more remarkable animal fossils are the trilobites (see marginal figure), long known under the appellation of "Dudley Fossils," from their frequent occurrence in the Dudley limestone. They are found so abundantly in the mountain limestone, in different parts of England, as to be characteristic of that formation. Specimens have also been discovered in Germany, Sweden, and North America. Another kind of trilobite (*Asaphus Debuchii*) is so abundant in some parts of Wales, that the laminæ of slates are charged with them, and millions probably lived and died not far from the places where we now discover their remains. A variety of conjectures have been hazarded with regard to these extinct animals,[*] which appear to have been Crustacea.

The crinoid animals constituted a once numerous class of zoophytes, some genera and species of which have continued up to the present day; while others, which are found in various rocks, have disappeared from among living animals. The lily encrinite (see marginal figure) belongs to the mountain limestone, and its remains form extensive strata of that rock, of which a representation has been given in a preceding page (409). In Lower Saxony and Westphalia, also, this stone is so abundant as to be used for building; and is composed like the Derbyshire marble chiefly of entrochal columns or stems of the encrinite; but specimens of the body are very rare. These animals were composed of a multitude of small bones, forming a vertebral column, probably attached at its basis to the surfaces of rocks, and surmounted by a cup, from the edge of which proceeded digitated processes, the removal of the outer portions of which, in the preceding figure, shows the cluster of tentacula by which they were terminated. The whole skeleton must have been involved in a thin fleshy covering.

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[*] See Parkinson's Organic Remains, vol. iii. pp. 271, 275.

Among the corals are found some genera of which there are existing species. The annexed figure represents a madreporite, from Steeple Ashton, in Wiltshire. "It appears to have been imbedded in a hard, close-grained limestone, of a pale yellowish colour, part of which, containing fragments of shells and other marine remains, still adheres to the madreporite. The madreporite itself is formed of a spathose substance strongly impregnated with iron; as is the case with all the fossil madrepores found at Steeple Ashton."*

Notwithstanding there is a relatively small proportion of organic remains in the submedial rocks, it is evident that they must have been deposited when the atmosphere was adapted to the vegetation of plants, and when the sea was capable of affording habitation and food for various kinds of animals; and though no remains of terrestrial animals have been preserved, it is at least probable that such existed, for whom the vegetables served as food. Of the marine animals, vast multitudes may have utterly perished, without leaving any traces behind. "Mere fleshy creatures may have existed in myriads, without any of them having been transmitted to us. In proof of this, if any were requisite, we may inquire what portion of those myriads of fleshy animals which now swarm in some seas (as the Medusæ), could be transmitted as organic remains to future ages."*

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* Parkinson's Organic Remains, vol. ii. p. 67.

Medial Rocks.

The formations of this class, constituting the "Medial Order" of Conybeare, are included among the Floetz or Flat Rocks of Werner, and by other geologists have been regarded as forming the lowest group of secondary rocks. They comprehend all the principal deposits of coal, or great coal-fields, at least in this country; and hence the term *carboniferous* has been generally applied to them. The lowest of these rocks, termed the Old Red Sandstone, contains but few organic remains; and so far as they have been observed, they appear to be of a similar character with those in the strata immediately below or next above this sandstone.

The Mountain Limestone, also termed Carboniferous Limestone, presents considerable analogies with the transition limestone, relics of corals and radiated animals being inclosed in it, especially those of the encrinites. It is usually of a grey colour, and granular, but sometimes of a foliated texture, particularly where it comes in contact with trap rocks. Some varieties are impregnated with bituminous or carbonaceous matter, and are of a black colour, as the marble called Lucullite. Lead ore, and occasionally the ores of zinc and copper, occur in this rock, which has therefore been called metalliferous limestone. It seems to be the most recent formation in which metals are found in veins, which seldom rise into the coal strata; and when they do they soon terminate, as in Durham and Northumberland, where strings of galena extend from the carboniferous limestone into the lower part of the coal formation.

The *coal-measures*, as they are technically termed, including the associated beds of shale, clay, and ironstone, compose the highest formation of medial rocks; though they are not exclusively confined to this series.* This valuable mineral is generally deposited in basin or trough-shaped hollows, of various extent, from one to many miles; and it sometimes covers large areas, which may at a distant period have been deltas over which great rivers dispersed immense piles of vegetable matter, such as are now collecting at the mouth of the Mississippi. The manner in which coal and the alternating strata are usually disposed has been described already, and illustrated by a section of the coal-basin in the hill of St. Giles, near Liege.† In the great coal-field of South Wales the strata are arranged in a vast trough, over a tract nearly 100 miles in length, and from 5 to 20 in breadth. It contains twenty-three beds of workable coal, the thickest nine feet deep; and in some parts there are sixteen seams or layers of ironstone.‡

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* De la Beche's Geol. Man., p. 420.

Dr. Hutton ascribed the formation of coal to accumulations of carbonaceous matter, from various sources, at the bottom of the sea; but geologists at present seem to be generally disposed to regard this mineral as a deposit from freshwater, consisting principally of vegetables, which became submerged in lakes, sometimes occupying the spot on which they had grown, and into which descending torrents washed the clays and sands forming the beds interposed between the several strata of coal. These depositories, however, must have been occasionally overflowed by the sea; for in some instances, beds of marine shells are found between those of coal.

That the coal strata have been partly formed by plants growing on the spot appears from the repeated examples which have been adduced of stems of trees found in coal-mines, in a vertical position with their roots imbedded in the strata below. Mr. Witham mentions the occurrence of such stems in the Derwent mine, near Blanchford, Durham; and of numbers of fossil vegetables, chiefly *sigillariæ*, erect, with their roots imbedded in a small seam of coal under the sandstone, and all truncated on the line of the High Main coal-bed, to the formation of which the tops probably contributed.[*] A curious instance of similar appearances is noticed by Mr. Wood, as having been observed at Killingworth colliery, in the same district. There were many fossil trees rising perpendicularly 10 feet through various strata of shale and sandstone. They were filled with sand, resembling that of the upper beds; so that they must have been hollow when those beds were deposited.[†]

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* "Le carbone n'appartient pas exclusivement au terrain houiller. Nous avons vu former des amas et des couches exploitables dans le terrain de transition, et il se présentera encore dans des formations postérieures; mais il y atteint son maximum d'abondance, et devient un caractère presque constant." —Burat *Traité de Geognosie*, tom. i. p. 274.

† See p. 393.

‡ Bakewell's Introduction to Geology, p. 152.

Mr. Witham, in a subsequent publication to that just quoted, has given an account of some interesting researches concerning the structure of fossil plants found in the carboniferous strata.

In the neighbourhood of Coldstream, on the banks of the Tweed, numerous fossil vegetables occur imbedded in shale, belonging to the carboniferous group. Stems of trees are found contorted and flattened, as if they had been subjected to extreme pressure. The longest stem obtained was not much more than 4 feet, and the lowest part of it about 6 feet in circumference.

"In 1826 an enormous trunk was exposed in the lowest bed of Craigleith Quarry, near Edinburgh, at the depth of upwards of 136 feet. The length of this trunk was 36 feet, and its diameter at the base 3 feet. It lay in a nearly horizontal position, corresponding with that of the stratum of hard white sandstone in which it was imbedded. It was incased in a layer of coaly matter, being probably the altered remains of the bark." From analysis it was found to be composed of carbonate of lime, 60 parts; oxide of iron, 18; alumine, 10; and carbonaceous matter, 9. Its interior structure resembled that of the Coniferæ.

"In November, 1830, a magnificent fossil stem was discovered in the same quarry, which, in geological position, is situated in the Mountain Limestone group, and lies considerably below the great coa basins of the Lothians."

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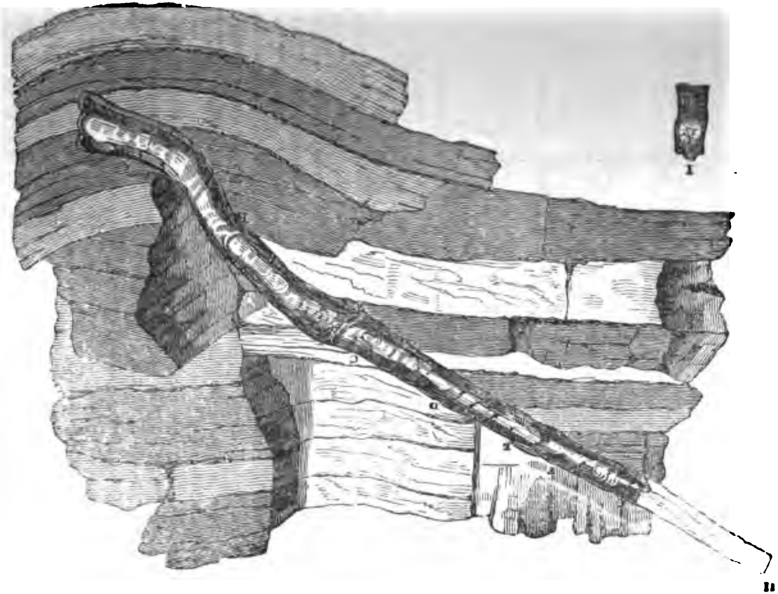
[*] Observations on Fossil Vegetables. 1831. p. 7.

[†] De la Beche, from Trans. of Society of Natural History of Newcastle, vol. i.; and Lindley and Hutton's Fossil Flora of Great Britain.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"The length of the stem (see preceding figure) from the base to the top was 47 feet. It presented the appearance of a large branchless trunk, in some parts greatly flattened, so as to form an elliptical section." Dimensions: A, diameter, 5 ft. by 2 ft.; B, C, 2 ft. 8 in. by 1 ft. 5 in.; D, E, 2 ft. 7 in. by 1 ft.; F, 1 ft. 10 in. by 1 ft. 3 in.; G, 1 ft. 7 in. by 1 ft. 4 in.; H, supposed prolongation of the top of the stem, 12 ft.; I, upper part of the tree first discovered, showing a cavity, the seat of a branch.

The superincumbent mass must have been above 100 feet in depth. The bark was converted into coal. This fossil also exhibits the usual structure of the Coniferæ, and appears from analysis to have consisted of—Carb. of lime, 62; carb. of iron, 33; carbon, 5.; sp. gr., 2.87.

A third fossil stem of a similar character was found in 1831, in the same quarry.*

Messrs. Lindley and Hutton, in their "Fossil Flora," vol. i. p. 9, pl. ii., have described the trunk of 1826 and that of 1830, under the appellation of *Pinites Withami*; and have named that of 1831. *Pinites Medullaris*.

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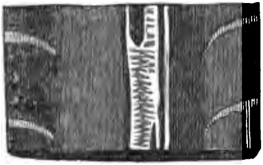
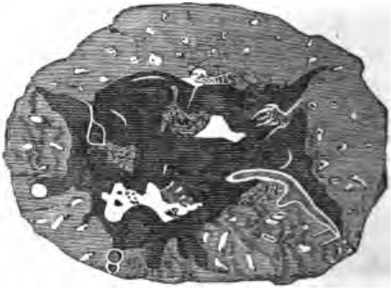
* Witham's Illustrations of Fossil Vegetables, sect. iii.

Mr. Witham received from the Rev. G. V. Harcourt some remarkable vegetable fossils from the Northumbrian coal-mines; one of which is shown in the preceding figure.

The specimens "consist of sub-cylindrical or slightly-compressed dichotomous stems. The surface is covered by a thick envelope of carbonaceous matter, presenting indistinct protuberances arranged in spiral series, and beneath which are observed papillæ of an elliptical form, higher than broad. The above figure represents a portion of one of the stems, denuded of its carbonaceous covering."*



The marginal figure exhibits a longitudinal section of a part of one of these fossils, in which the central axis or pith is entirely filled by calcareous spar, and a tube of carbonaceous matter. From the axis emanate, on all sides, cylindrical processes, consisting of cellular tissue, with central fasciculi of vessels. They proceed obliquely upwards and outwards, and terminate in the papillary eminences on the surface of the stem.†



These processes are seen cut obliquely in the foregoing figure, representing a transverse section of the stem, the processes appearing as white oblong markings dispersed in the brown parenchymatous tissue.*

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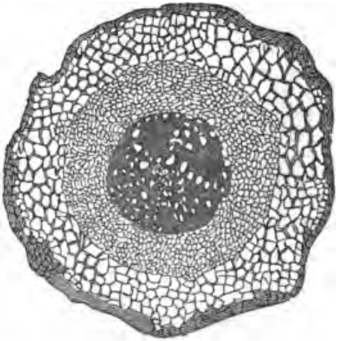
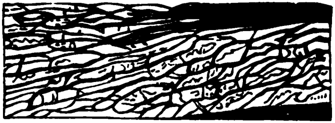
* Witham's Illustrations, p. 52. † Idem, ibid.

The plant evidently belongs to the vascular cryptogamic class, and appears to be allied to the Lycopodia.



The preceding figure represents a transverse section of the *Lycopodium Clavatum,* exhibiting the same kind of cellular structure and central axis, as appears in the fossil stem.



An oblique section of a process of the *Lycopodium Clavatum,* showing the structure of the tissue, of which there are traces in the fossil.†

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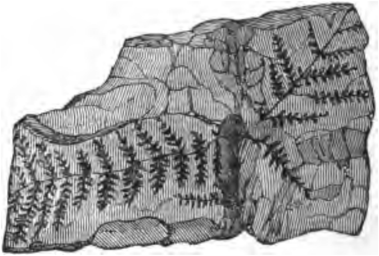
* Witham's Illustrations, p. 53.

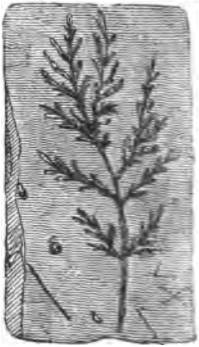
† Besides the preceding, Mr. Witham has given several other interesting magnified sections of different parts of these fossils.

To the plant which produced the Northumbrian fossils, Mr. Witham has assigned the name of *Lepidodendron Harcourtii*. He has examined and described the structure of fossil plants belonging to four distinct genera: Pinites, Pitus, Anabathra, and Lepidodendron; including nine species.

From the sections of fossil stems found in the coal strata and mountain limestone, he infers that "these combustible beds were masses of vascular and cellular cryptogamic plants, mixed with gymnospermous phanerogamic trees, or others of a closely-allied structure;" and not entirely of vascular cryptogamic vegetables, as some have supposed.*

Branches and leaves of plants, especially of ferns, are abundant in the coal-measures and the formations with which they are connected. Numerous specimens are preserved in the British Museum; two of which are exhibited in the following figures.





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* Illustrations, sect. i. p. 10.

Supermedial Rocks.

The Penean or lower group of these rocks consists partly of new red sandstone, with beds of marl, and also gypsum and rock salt; and in the bituminous copper slates are found the first traces of those immense reptiles of the lizard family, which are so abundant in the liasic group. The zechstein or magnesian limestone contains only a few genera of plants, several of shells, mollusca, radiaria, and zoophytes, three of fishes, and one reptile.

In the Keupric group occurs a greater variety of plants and animals, including among the latter five or six genera of saurian reptiles. Among the organic remains of the muschelkalk, two of the most characteristic are perhaps the *Ammonites nodosus,* and the *Encrinites moniliformis*, or Lily Encrinite; but the former is also found in the higher, and the latter in the inferior rocks. This limestone has not been met with in Britain; but its characteristic fossils occur in the red marls and sandstones, by which it seems to be replaced. Among these, likewise, are beds of rock salt; and from the presence of that useful mineral in this and the preceding group, they have been described together by some geologists, under the appellation of the "Saliferous System."*

The formations which constitute the two following groups (the liasic and the oolitic), are peculiarly rich in fossil remains. Among those of vegetable origin are lignites, fossil wood, sometimes siliceous, impressions and casts of ferns (see p. 413), cycadaceæ, and fuci. But these are not the only kinds of plants. Mr. Witham found in these groups three species of a genus named *Peuce*, peculiar to the lias and oolite, or at least not occurring in anterior deposits; and two species of *Pitus*, which also appear in the mountain limestone. From an examination of these fossil trees, he ascertained that their tissue, in transverse sections, corresponds precisely with that of our Coniferæ, and more especially with that of the genus *Pinus*.

From the circumstance that the concentric layers of the fossil vegetables, which Mr. Witham has described as occurring in the lias and oolite, being like those of recent trees, some much broader than others, he infers, that the climate which existed at the epochs when these vegetables grew, resembled ours in the irregularity of its successive summers. "The Coniferæ of the coal formation and mountain limestone group have few and slight appearances of the lines by which the annual layers are separated; which is also frequently the case with the trees of our present tropical regions. It is therefore possible, that at the epochs of these formations, the changes of season, as to temperature, at least, were not abrupt."* Hence it may be concluded, that the climate of these latitudes, which resembled that of tropical countries when the vegetables forming the coal strata flourished, had become more temperate and variable during the growth of the plants imbedded in the liasic formations.

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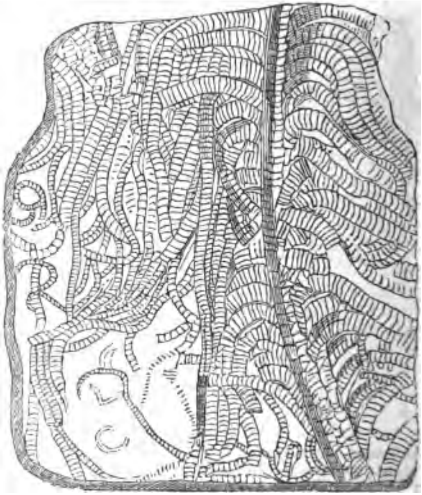
* See Encyclopædia Metrop.—Mixed Sciences, vol. iv. p. 608.

But the groups now under consideration are most remarkable on account of their animal fossils, which are numerous and interesting. In the lias the crinoid radiaria again make their appearance.



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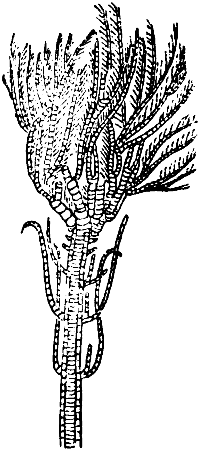
* Illustrations of Fossil Vegetables, p. 58.

The Briarean Pentacrinite is one of those animals the remains of which are most common in this country. The preceding figure exhibits part of the vertebral column, and articulated processes connected with it. These fossilized animals were akin to the encrinites, from which they are characteristically distinguished by the shape of the bones composing the spinal columns. In the encrinites they are circular disks, as may be perceived by turning to the figure, p. 421, in which several of these bones are shown imbedded in mountain limestone. The bones of the pentacrinite are pentangular. Multitudes of them are found detached in the formations of the liasic and oolitic groups, and in the higher strata: from their figure they have been named *Astroites*, or star-stones; and they are so often met with at Lassington Hill, near Gloucester, that they have obtained the provincial appellation of "Lassington stones."



The Pentacrinite is one of those fossil animals, of which there are probably living analogues. The marginal figure represents the upper portion of a radiated animal, described by M. Guettard, from a specimen given by a French officer, who had been at Martinique, to a lady at Paris.* A pentacrinus, differing from the preceding, is also said to have been recently discovered in the West Indies; and a smaller species more lately in the Cove of Cork.†

But among the singular organic remains derived from animals which occur in these groups, the gigantic and monstrous lacertæ deserve particular notice. Some of these inhabited the waters; and others flitted through the air like birds, or rather bats.

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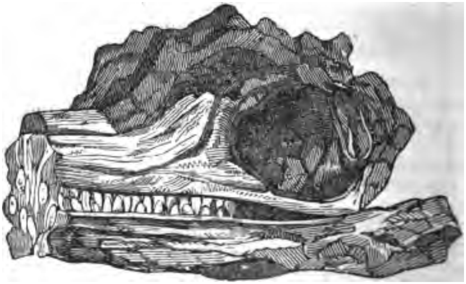
* V. Mém. de l'Acad. des Sciences de l'ann. 1755.

† Bakewell's Introduction to Geology—Prelim. Obs., p. xxxv. Mr. Bakewell has given a representation of the latter pentacrinus, from a drawing by Mr. J. V. Thompson, of Cork.

The Ichthyosaurus, so called from its partly resembling a fish and partly a lizard,* had a head like the latter, terminating anteriorly in a long pointed muzzle, armed with numerous conical teeth. It had a long tail, capable of extensive vibratory motion; and its extremities were furnished with paddles of a peculiar construction. (See subsequent figure of the Plesiosaurus.) Several specimens of the Ichthyosaurus have been discovered; and the relics of some of them are preserved in the British Museum.

The succeeding figure represents a part of the head of the *Ichthyosaurus Latifrons*, from that repository. The socket of the eye measures about 9 inches across, whence an idea may be formed of the enormous size of the animal to which this head belonged. The *Ichthyosaurus communis* sometimes exceeded 20 feet in length; the *I. platyodon* appears to have had jaws 8 feet in length; and the *I. immanis* was a gigantic species, of which there are the lower part of one of the leg-bones, and several bones belonging to the paddle, at the British Museum.



The Plesiosauri constituted another genus of these strange swimming lizards. Its limbs have analogies with those of the foregoing animal; but more elongated and flexible. What, however, especially distinguishes it from all oviparous and viviparous quadrupeds, is a slender neck, as long as its body, composed of thirty and odd vertebræ. An idea of its general form may be obtained from the following figure, representing the *Plesiosaurus Dolichodeirus.*

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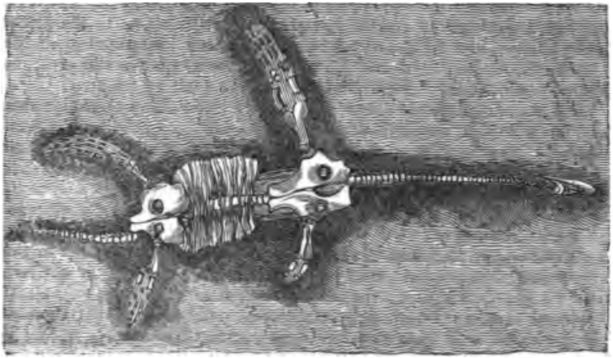
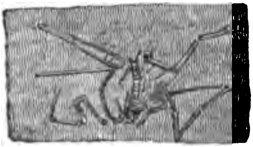
* From the Greek Ιχθυς, *a fish*, and Σαυρος, *a lizard*.



"If any thing," observes Cuvier, "could justify those hydras and other monsters, the figures of which are so often presented in the monuments of the middle ages, it would incontestably be this plesiosaurus."*

A more grotesque and monstrous animal than either of the preceding, is exhibited in the annexed figure of the fossil skeleton of a Pterodactyle, or Flying Lizard. These fossils are not very common: they are found in the limestone slates of the liassic group, at Solenhofen, in Germany; at Stonesfield, in Oxfordshire, and at Lyme Regis, in Dorsetshire. One species was about the size of a thrush, another of that of a common



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* Theory of the Earth, p. 257. For descriptions and figures of various species of Ichthyosauri and Plesiosauri, see Cuvier Récherches sur les Ossemens Fossiles, tom. v. pt. ii.

bat; and the remains have been discovered of some of larger dimensions.*

The Wealden Group is not less remarkable than the preceding, for its fossil remains. Among those of vegetable origin may be mentioned the silicified trunks of coniferous trees, and plants allied to the recent genera *Cycas*, and *Zamia*, which have been found a stratum called the *dirt-bed*, in the Isle of Portland. Many of the stems are still erect, as if petrified while growing undisturbed in their native forest.†

But the animal fossils discovered by Mr. Mantell among the strata of Tilgate Forest, in the Weald of Sussex, are more curious and interesting. Besides relics of crustaceous and testaceous animals and fishes, he has been enabled to recognise those of immense saurian reptiles; some of which were before unknown. To one of these animals he gave the appellation of Iguanodon, from its affinity to the Iguana. From the form of its teeth it appears to have been herbivorous; and a comparison of its bones with those of the recent Iguana, led to the conclusion, that it must have been fourteen times as large, or not less than 70 feet in length.‡ Another specimen of this gigantic animal has been recently found, near Maidstone, consisting of vertebræ of the back and tail, numerous toe-bones, some of which are 16 inches long, two claw-bones of peculiar form, two thigh-bones of great length, one leg-bone, two clavicles, two bones of the chest, and many others. It is said to have been very appropriately presented to Mr. Mantell.§

In the summer of 1832, workmen employed in quarrying the Tilgate grit, found a hard block, in which were imbedded a number of fossil bones. These being examined by Mr. Mantell, were ascertained to have belonged to a new saurian animal, which he described in a paper read before the Geological Society, and afterwards published. He gave to this creature the name of *Hylæosaurus*, or Wealden Lizard. It must have been from 20 to 30 feet in length; and appears to have resembled the recent *Iguana Cornuta*, in being armed with a horn on the forehead, and a row of spines along the back: it had an immensely long tail, and its body was covered with scales; whence it has been proposed to call it *Hylæosaurus Armatus*.||

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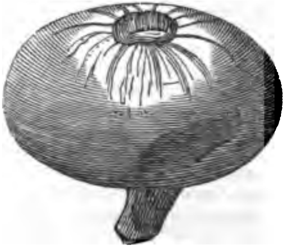
* V. Cuvier Recherches, u. a.

† See Mantell's Geology of the South-east of England, chap. xi.

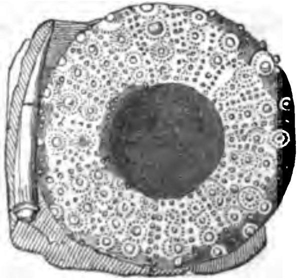
‡ Idem, pp. 304—316. § Globe Newspaper, Sept. 23, 1834.

|| See Geology of South-east of England, pp. 316—328.

In the formations of the Cretaceous Group are abundance of organic remains of vegetables and animals. Besides numerous shells, and relics of radiated animals, molluscs, and crustacea, there are in these strata some curious zoophytes. Among the fossils that may be regarded as characteristic of this group may be mentioned, alcyonites, echinites, ammonites, and belemnites.



The marginal figure represents a fig-formed alcyonite, of a dark red colour, where the surface is not concealed by its cortical coat, which is grey, pervaded by a slight tinge of red. "The pedicle and the opening at the superior part are here very perfect. Slight traces of lines, passing from the pedicle to the opening, are discoverable in this specimen, and doubtlessly point out the arrangement of fibres by which the animal was enabled to draw in and eject the water which supplied it with food."* "The recent animal, according to Count Marsigli, is of the form of a fig, being attached to the rocks by branches proceeding from its smaller end; its upper part being a little flattened, with a hole in the centre. Its colour resembles that of tobacco; and its parenchymatous substance, he thinks, cannot be compared to any thing better than to nutgalls, when well dried."



An echinite, from the Kentish chalk pits, with one of its spines, is exhibited in the annexed figure. Various species of the genera *Echinus* and *Cidaris* are found fossilized in Wiltshire, and other southern counties, where the black flint most abounds. These animals, sometimes called Sea-eggs, are common in a recent state.

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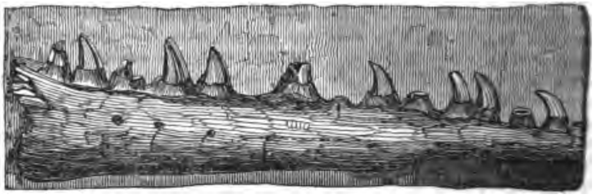
* Parkinson's Organic Remains, vol. ii. pp. 96, 97.

Two genera of saurian reptiles in the fossil state occur in the cretaceous rocks. These consist of a species of crocodile, found at Meudon, in France; and the Mososaurus, remains of which were first discovered in the quarries of St. Peter's Mountain, near Maestricht; and since near Lewes, in Sussex. This creature appears to have been nearly 24 feet in length.*



The preceding figure exhibits a representation of a fragment of the lower jaw of this saurian monster, preserved in the British Museum.

Tertiary Rocks.

In the formations above the chalk, the organic remains increase in number and variety; though many fossils found in the lower series no longer occur. Only a few of the most remarkable can be noticed here. Extensive catalogues of shells, distinguishing their localities, their living analogues, where they are known, and the relative ages of the deposits in which they are found, have been published by M.

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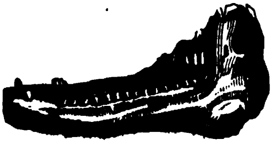
* See Mantell's Geology of South-east of England, pp. 146—152; and Cuvier Recherches, tom. v. pt. 4.

Deshayes and Mr. Lyell.[*] The *Cerithium Giganteum*, which is remarkable for its size, is found in the London and Paris basins.

"The most extraordinary shell of this genus (*Cerithium*) is *C. giganteum*. It is turreted, extremely long, and transversely striated: the turns in their upper part are tubercular, and the columella has one fold. These enormous shells are generally a foot in length. One of the specimens which I possess, and which has lost at least an inch or two of its length, still measures 14 inches. They are found at Grignon, and are not very rare: they are, however, in general, very much injured; very seldom indeed having the lip and sides open and perfect. Their form is that of a winding turriculated pyramid, with in general twenty turns, beset on their upper part with a row of nodular tubercles, and having the general surface lightly and transversely striated. The opening is oblong and oblique, and terminates in the lower part in a canal, the extremity of which is moderately recurved; and the superior part, instead of forming a canal, is laterally extended, in the manner of an ear-like process. There is only one fold on the columella. This is, undoubtedly, the largest unilocular univalve shell that is known."[†]

During the long period of the deposition of the tertiary formations, quadrupeds existed; several of which, now extinct, display peculiarities of form and structure. To the researches of Cuvier we are indebted for the discovery of the genera of the *Palæotheria*, *Lophiodonta*, *Anoplotheria*, *Anthracotheria*, *Chæropotami*, and *Adapis*.



The marginal figure represents a lower jaw of the *Palæotherium Maximum* of Cuvier, which, together with other remains of palæotheria and anoplotheria, are preserved in the British Museum. "The palæotheria must have resembled the tapirs, among recent animals, in their general form, and in that of the head, particularly in the shortness of the bones of the nose, which announces that they must have had a small proboscis like the tapirs, and lastly, in their having six incisors and two canine teeth in each jaw; but they resembled the rhinoceros in their grinders (of which those of the upper jaw were square, with prominent ridges of various configuration, and those of the lower jaw in the form of double crescents), as well as in their feet; all of which were divided into three toes, while in the tapirs the fore feet have four. It is one of the most extensively-diffused genera, and most numerous species that occur in the deposits of this period."[*] The bones of these extinct quadrupeds are found in the gypsum quarries of Paris, and in other parts of France.

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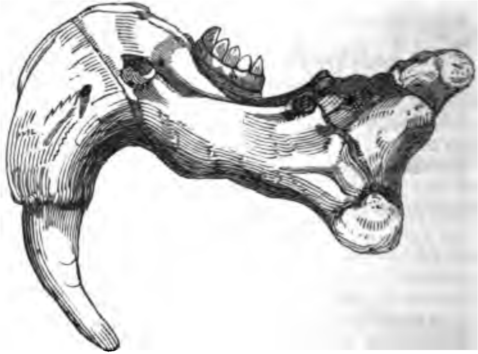
[*] Deshayes Description des Coquilles caractéristiques des Terrains. Paris, 1831. Lyell's Principles of Geology, vol. iii. 8vo. 1st edit.

[†] Parkinson's Organic Remains, vol. iii. p. 71.

Among the fossils of the British Museum are the lower jaws of different species of *Deinotheria*, part of an upper jaw, and detached teeth; from Eppelsheim, in Germany.



The above figure exhibits a lower jaw of the *Deinotherium Giganteum*, some of the teeth of which are wanting; but in which is seen one of the very singularly-formed tusks, or weapons with which nature had armed this quadruped.

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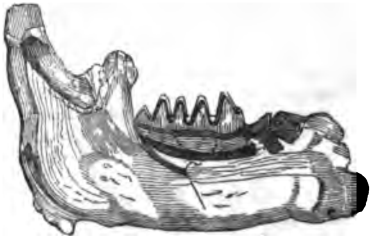
[*] Cuvier's Theory of the Earth, p. 266. See also Recherches, tom. iii. and tom. v. pt. ii.

Alluvial Deposits and Bone Caverns.

The remains of several animals no longer in existence, mingled with those of living species, occur in the relatively recent formations. Among these, the Mastodon Ohioticus has attracted particular attention. The earliest notice that occurs of this animal is in a letter from Dr. Mather, of Boston, in New England, to Dr. Woodward;* and in 1740, relics of the Mastodon were found in Kentucky, on the banks of the Ohio. Immense quantities of its bones have since been discovered in North America. The marginal figure is a representation of a lower jaw of the M. Ohioticus, from the British Museum. It measures about three feet along the base. Cuvier says, the great mastodon was as high in proportion as the elephant, with equally long tusks, and had grinders covered with bristling points, which made them long be considered as those of a carnivorous animal. Its bones were extremely large and solid. Its hoofs and stomach are said to have been found in such a state of preservation as to be recognisable; and it is asserted, that the stomach was filled with bruised branches of trees. The Indians imagine that the whole race was destroyed by the gods to prevent them from destroying the human species. This seems to be a proof that the mastodon was extinct before America was inhabited by man; or else the Indians could not have mistaken this phytovorous quadruped for a beast of prey.†



The fossil elephant, called by the Russians the Mammoth, was another of the ancient pachydermata, thousands of the carcasses of which were dispersed over the surface of the earth, from Spain to the shores of Siberia, and throughout North America. It was one of this species that was found in the beginning of the present century, at the mouth the river Lena, preserved in ice, and of which the skeleton was removed to St. Petersburgh. This animal differed from the modern elephants, in having a thick coat of long hair on its body: it was more than 9 feet high, and 16 in length.*

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* See Philos. Trans., abridged by Jones, vol. v. pt. ii. p. 159.

† V. Recherches sur les Oss. Foss., tom. i. and tom. iii.

To this period has been assigned the Megalonyx, a quadruped whose bones have been found in the western part of Virginia, in a cave in the county of Green Briar, three feet beneath the surface of the ground. This creature, from its teeth and claws, appears to have resembled the sloths and anteaters; but in size it must have equalled the largest oxen.

The Megatherium, the relics of which have been discovered in South America, exhibits an union of the characteristics of the armadillos and the sloths, with the magnitude of the rhinoceros. Its claws must have been of a monstrous length, and prodigiously strong; and its whole frame displays excessive solidity. A skeleton of this animal, found at Buenos Ayres, was sent to Madrid in 1789; and one more recently discovered in Paraguay, was brought to England by Mr. Woodbine Parish, and presented to the Royal College of Surgeons.†

Contemporary with these and other animals, the genera of which are become extinct, were hyenas, bears, tigers, wolves, and other beasts of prey differing only in species from those now existing. At this epoch, remarks Cuvier, "the class of carnivora was numerous and powerful." The palæotheria, and other mammalia and reptiles of the tertiary period, having been destroyed by some convulsion of nature, were replaced by a brute population of a different character, and these in their turn were extirpated by an overwhelming catastrophe, which must have preceded the origin of the human race.

The bone caverns, with their contents, and the osseous breccia found in other situations, present phenomena connected chiefly with the geological formations posterior to those of the tertiary period. Caves containing the bones of bears and other animals have been long since noticed in Germany. The most anciently celebrated is Baumanshole, in the country of Blankenburg, described by many authors, and especially by Leibnitz, in his "Protogæa." It is formed of several caverns, containing abundance of stalactites, and the bones of animals, principally bears. The caves of Gaylenreuth in Franconia, and Adelsberg in Carniola, have also attracted much attention; and there are many others, but it does not appear that among the bones found in them there were any of animals belonging to the lost genera.*

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* See Brande's Journal of Science, vol. viii. p. 96; and Cuvier Recherches, tom. i., iii. The soft parts of this animal had been so completely protected from decomposition, during a long series of ages, by the frozen matter in which it was enveloped, that the flesh was devoured by bears and other beasts of prey, after its release from its icy sepulchre.

† For an account of the Megalonyx and Megatherium, see Cuvier Recherches, tom. v. pt. i.

In England several bone caverns have been observed; as that of Kirkdale, in Yorkshire, discovered in 1821, and examined a few months afterwards by Professor Buckland. The floor of this cave was formed of argillaceous and slightly micaceous loam, mixed with much calcareous matter, and coated with stalagmite; beneath which were buried bones and teeth of the hyena, tiger, bear, wolf, fox, weasel, elephant, rhinoceros, hippopotamus, horse, hare, rabbit, water-rat, and mouse; raven, pigeon, lark, a small kind of duck, and a bird about the size of a thrush. From the manner in which these relics were dispersed over the bottom of the cavern under the mud deposit, and the great preponderance of hyenas' teeth among the bony fragments, Dr. Buckland concluded that this place had been a den of hyenas, at a remote period, when tigers, elephants, and hippopotami, were among the brute population of this part of the surface of the globe; and that the hyenas had brought in the bones of other animals which they made their prey; and that this state of things was suddenly terminated by an irruption of a diluvial torrent, which buried the drowned and previously-destroyed animals in an envelope of mud.†

There are also ossiferous caverns in France, which have excited particular attention on account of the occurrence of human bones in them, together with those of other animals. In the cavern of Bize, in the department of Aude, M. Marcel de Serres met with a small number of human bones, mixed with those of extinct animals and with land-shells; in a calcareous, stony mass, cemented by stalagmite. M. Tournal also found in this mass and the black mud above it, human teeth, and the fragments of rude pottery.* In caverns in tertiary limestone, at Poudres and Souvenargues, in the department of Herault; and in a cavern near Miallet, in the department of Gard, human bones and coarse pottery have been discovered, mingled with the relics of lost animals.† These phenomena gave rise to a controversy as to the probability of man having been contemporary with the brutes with whose remains his own are now intermixed. After noticing the arguments on both sides, Mr. Lyell observes, that "as many of these caverns may have served in succession as temples and habitations, as places of sepulture, concealment, or defence, it is easy to conceive that human bones, and those of other animals in osseous breccias of much older date, may have been swept away together by inundations, and then buried in one promiscuous heap. It is not on the evidence of such intermixtures that we ought readily to admit either the high antiquity of the human race, or the recent date of certain lost species of quadrupeds."‡

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* See Prof. Jameson's Geological Illustrations of Cuvier's Theory of the Earth. Note *on Caves containing Bones of Carnivorous Animals.*

† See Buckland Reliquiæ Diluvianæ.

Osseous breccias are not confined to caverns. They occur frequently in places on the northern shores of the Mediterranean and its islands. At Cagliari, Sardinia, such breccia is found in the clefts and small caverns of a tertiary rock, about 150 feet above the level of the sea. Dr. Christie describes such a deposit at San Ciro, near Palermo, as not being confined to the cave itself, but as forming part of the external talus, resting upon the upper tertiary beds, with a thickness of about 20 feet. The bones were those of the elephant, hippopotamus, deer, and of the dog. At Gibraltar have been observed breccia, formed by the bones of small animals, which seem to have been thrown down from the nests of hawks, which build in fissures of the rock. They are cemented together with fragments of decomposing limestone by ferruginous matter. In New South Wales osseous breccias have been found, including the bones of animals now known to exist in that country.

When the bones of elephants and other large quadrupeds were found imbedded in the earth in the middle ages, it was conceived by the credulous naturalists of that time that these were human relics. In 1577, Felix Plater, professor of anatomy at Basle, described several fossil bones of the elephant, found at Lucerne, as those of a giant at least 19 feet high. Some immense bones having been discovered in 1613, near the castle of Chaumont, in France, a surgeon of Beaurepaire, named Mazurier, procured them, and made a public and no doubt a profitable exhibition of them, as the remains of a gigantic king of the ancient Gauls, pretending that they had been inclosed in a sepulchre 30 feet in length, bearing the inscription, "TEUTOBOCHUS REX." The bones, however, were those of an elephant. At a subsequent period, Scheuchzer, a Swiss philosopher, brought forward an example of a skeleton of more moderate dimensions, imbedded in hard stone, which he represented as the undoubted relics of a human antediluvian. He published an abridged account of this wonderful fossil, in the Philosophical Transactions, 1726; and he made it the subject of a distinct treatise, entitled "*Homo testis Diluvii.*" Cuvier, at length, ascertained that this alleged anthropolite (the nature of which had been questioned by Camper and others) was a petrified lizard, a large extinct species of salamander.*

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* M. de Serres Geognosie des Terrains Tertiaires; ou Tableau des Principaux Animaux invertébrès des Terrains marins tertiaires du Midi de la France. 1829.

† Bulletin de la Société Géologique de France, tom. ii.

‡ Principles of Geology, vol. iii. p. 165.

There is, however, at the British Museum, a genuine anthropolite, brought from Guadeloupe, in the West Indies. It consists of a considerable portion of the skeleton of a woman (the spine, pelvis, several ribs, one arm, the leg and thigh bones) imbedded in a block of calcareous stone. The stone is a kind of travertin, formed of land-shells, slate, and fragments of shells and corals from the sea; which, like the formations of a similar composition found on the limestone coasts in some parts of this country, has acquired a great degree of hardness. It is consequently a recent petrifaction in an alluvial formation.† Other skeletons, probably those of Caraibs, are contained in the same calcareous rock; and one, with a portion of the head remaining, is preserved in the Museum of Natural History at Paris.

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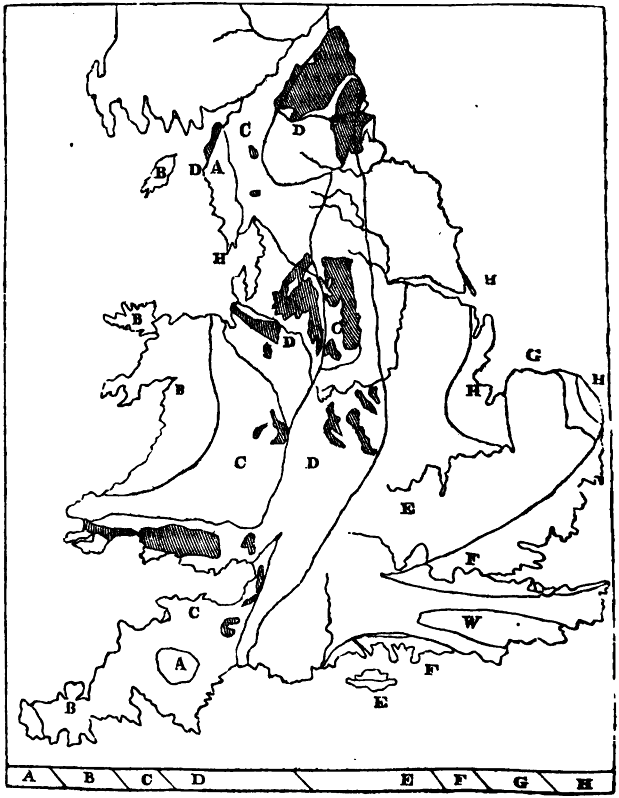
* Bertrand Lett. sur les Rev. du Globe, lett. ix. xvi.

† Jameson's Illustr. of Cuvier, pp. 406—410.

GEOLOGICAL MAP OF ENGLAND AND WALES.



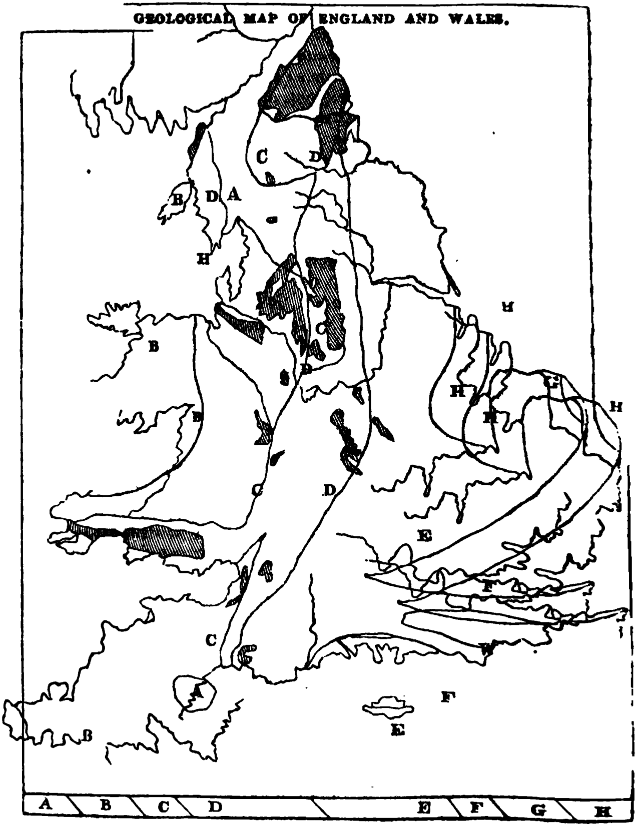
The preceding map is merely intended to afford a very general outline of the superficial extent of the great formations of this country. It will appear, from inspection of this sketch, that the earlier rocks and strata prevail on the western side of the island, and those of more recent origin on the eastern side; whence it may be supposed, that the primordial and submedial rocks once formed mountain peaks or ridges rising from the sea, which covered those tracts that now constitute the downs and levels of the eastern and southern counties. A. Primordial Rocks. B. Primordial and Submedial Rocks. C. Submedial and Medial Rocks. D. Chiefly Supermedial Formations below the Chalk. E. Supermedial Formations, including the Chalk. F. Formations of the London Basin. G. Norfolk Crag. H. Alluvial Deposits. W. Wealden District: (formations immediately below the Chalk.) The letters on the margin indicate the order of superposition of the respective classes of formations. The order of these formations is never inverted; though the higher ones are sometimes wanting, as in the Wealds of Sussex, where the Hastings sands and clays are immediately covered by alluvial soil. The shaded parts of the map denote the situations of the principal coal deposits.

Most of the English coal-fields lie between the great mountain chains of primitive and transition rocks on the west, and the chalk hills and downs on the eastern side of the island in the tract of country covered by the supermedial formations below the chalk. Westward of these deposits are the great coal-fields of South Wales, bordering on the Bristol Channel. The whole of the British coal-fields south of the Tweed are thus arranged and distinguished by Mr. Conybeare.

I. COAL DISTRICT NORTH OF TRENT, OR GRAND PENINE CHAIN.

Coal Formations of Northumberland.
Durham.
N. of Yorkshire.
S. York, Nottingham, and Derby.
S. Derby.
N. Stafford.
S. Lancashire.
N. Lancashire.
Cumberland and Whitehaven.
Foot of Crossfell.

GEOLOGICAL MAP OF ENGLAND AND WALES.



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Foot of Crossfell.

II. CENTRAL COAL DISTRICT.

Coal Formations of Ashby de la Zouch.
Warwickshire.
S. Stafford or Dudley.
Indications near the Lickey Hill, &c.

III. WESTERN COAL DISTRICT.

North Welsh—Isle of Anglesea.
Flintshire.
Mid-western or Shropshire—Plain of Shrewsbury.
Coalbrook Dale.
Clee Hills and S. Shropshire.
South-western—In S. Wales.
Forest of Dean.
S. Gloucester.
Somerset.

London is chiefly supplied with coal from the mines of Northumberland and Durham. According to Dr. Thomson, these counties may continue to furnish fuel for the consumption of the metropolis, at the same rate as at present, for a thousand years to come. Mr. Bakewell, however, states, that these northern mines will be exhausted in about three hundred and fifty years; but he alleges, that the great coal-fields of South Wales will supply England with fuel for two thousand years, after all the English coal-mines are worked out.

METEOROLOGY.

WHERE THE DUTIES OF THE GEOLOGIST TERMINATE THOSE OF THE METEOROLOGIST MAY BE SAID TO BEGIN. TO HIM IT BELONGS MORE ESPECIALLY TO CONSIDER THE GLOBE IN ITS PRESENT CONDITION OF QUIETUDE OR EQUILIBRIUM, AND THE MEANS BY WHICH THIS STATE OF EQUILIBRIUM IS MAINTAINED: IN PARTICULAR, TO POINT OUT THE INFLUENCES OF HEAT AND LIGHT, AND OF THE ENERGIES ALLIED TO THEM; TO STUDY THE LAWS OF DISTRIBUTION, AND CHANGE OF THESE IMPORTANT AGENTS IN THE PRODUCTION OF CLIMATE; TO TRACE, IN SHORT, THE EFFECTS OF THESE WONDERFUL PRINCIPLES UPON THE EARTH, THE OCEAN, AND THE ATMOSPHERE, AND ALL THE INFINITE VARIETY OF THE PHENOMENA DEPENDENT UPON THEM.

Chemistry, Meteorology, &c., considered with reference to Natural Theology. By W. Prout, M.D. 1834.

METEOROLOGY.

There are few subjects connected with Natural Philosophy which are more generally interesting than that which is about to engage our attention. Meteorology may be considered as a science supplementary to Geology; and as the latter relates to the state and constitution of the terrestrial globe, so the former regards the composition of the atmosphere, and the investigation of the constant changes that are taking place in it. "The quality of the air, as affected by cold or heat, moisture or dryness, and other circumstances, is distinguished by the term weather. The knowledge of the alterations of the weather, and of the laws by which they are governed, is styled weather-wisdom (*die Witterungslehre*), or Meteorology. This science is yet very imperfect, and requires for its improvement numerous and extensive observations."[*] Notwithstanding, however, the confessedly defective state of this branch of physical science, it is certainly one which has occupied the attention of mankind in various ages, and in several different parts of the world; but it is only in our own times that it has been studied with the attention due to it, both in an economical and in a philosophical point of view. To the navigator, the traveller, the husbandman, and numerous other classes of persons, the state of the weather, and the anticipation of the probable changes that may occur in it, must ever be topics of considerable interest and importance; while the scientific inquirer will feel no less anxious to trace the laws by which meteorological phenomena are regulated, and to study their connexion with those of Astronomy and Geology.

One of the latest and most distinguished of our meteorological writers remarks, that "man may almost with propriety be said to be a meteorologist by nature: he is naturally placed in such a state of dependance on the elements, that to watch their vicissitudes and anticipate their disturbances becomes a necessary portion of the labour to which he is born. The daily tasks of the mariner, the shepherd, and the husbandman, are regulated by meteorological observations; and the obligation of constant attention to the changes of the weather has endued the most illiterate of the species with a certain degree of prescience of some of its most capricious alterations. Nor in the more artificial forms of society does the subject lose any of its universality of interest: much of the tact of experience is blunted and lost; but artificial means, derived from science, supply, perhaps inadequately, the deficiency; and the general influence is still felt and acknowledged, though not so accurately appreciated. The generality of this interest is, indeed, so absolute, that the common form of salutation among many nations is a meteorological wish, and the first introduction between strangers a meteorological observation."[†]

Meteorology, in its most extensive acceptation, has for its object not merely the observation of atmospherical phenomena, or of those occasional appearances styled meteors, to which the attention of common observers has been generally limited, but it likewise includes the *rationale* of terrestrial as well as atmospherical phenomena, whether accidental or permanent, which depend on the action of heat, electricity, magnetism, or light. Considered in this point of view, the subject will appear to be of immense extent; and it may hence be characterized as the application of the laws of Pyronomics, Optics, and Electro-magnetism to the study of nature. To take any thing like a complete survey of the science in all its bearings, would not only require a much greater space than the plan of this work will allow, but would also render it necessary to repeat much that has been introduced elsewhere, in illustration of topics discussed in some of the preceding treatises, both in the former and in the present volume. This essay on Meteorology will therefore be confined to the investigation of the influence of moisture and temperature, on the state of the atmosphere, and the explanation of the nature and causes of the most important meteorological phenomena, with references to such subjects as have undergone previous discussion.

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[*] Elements of Natural Philosophy, by Prof. Vieth, (Germ.) p. 408.

[†] Daniell's Meteorological Essays and Observations. 2d edit.

The general properties of the atmosphere, as a permanently elastic fluid encompassing on all sides the solid globe of the earth, and indefinitely extended from its surface, have been pointed out and illustrated in the treatise on Pneumatics. It has been stated, that at the height of fifty miles the air does not possess sufficient density to reflect the rays of light; and though it is not improbable that the atmosphere may exist at a still greater elevation, yet the speculations of Dr. Wollaston go far to prove that it must have certain limits, beyond which the ethereal medium must be of such extreme tenuity as to occasion no appreciable resistance to the revolutions of the planets round the sun: for if they revolved in a resisting medium, like the air, the regularity and uniform extent of their orbits would be disturbed, contrary to what may be concluded from a comparison of astronomical observations made at different and remote periods.* The peculiar temperaments of various organized beings qualify them respectively for the several situations they inhabit. The deepest abysses of the sea are probably destitute of animated beings, but the gigantic whale can descend to a vast depth beneath the surface of the ocean, though breathing the air like man, and consequently unable to remain deprived of it but for a comparatively short period; and the polype lays the foundation of his coral cells on rocks often apparently far beneath the usual abodes of the finny tribes. On the other hand, the condor dwells in the upper regions of the air, and wings his steady flight over the summits of Pinchincha or Chimborazo, which are among the loftiest peaks of the mighty Andes. Inflamed bodies would become extinguished for want of air at the height of about 20,000 yards above the sea; hydrogen gas would no longer deserve the name of inflammable air at 25,000 yards; and sulphur would be incombustible at 30,000 yards, if it was possible for it to be transported to such an eminence.

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* It should, however, be remarked, that the observations of astronomers during a period of even two thousand years, can afford no conclusive evidence of the non-existence of a highly attenuated but resisting medium, beyond the atmospheres of the earth and other planets. For though it may require a lapse of millions of ages before the orbits of these dense bodies can be sensibly affected by the medium they traverse, yet lighter bodies, such as comets are supposed to be, may afford indications that the celestial space is not an absolute vacuum. See Treatise on *Geology*, p. 314.

The temperature of the atmosphere diminishes in proportion to the elevation above the level of the sea. The degree of temperature, however, is further influenced by other causes, and should be estimated with reference to the normal heat of plains, whence may be deduced the direction of isothermal lines for summer and winter;* depending more or less on the mass and configuration of mountains; the strata of clouds or vapours which may intercept the radiation of heat from plains below; and likewise on the winds or currents of air passing horizontally from one zone to another of a different temperature.†

The gravity of the air, and the continual variations taking place in it, are among the most important causes of several atmospheric phenomena. Abundance of facts demonstrate that the weight of a column of air, of any given diameter, is equal to that of a similar column of water

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* These have been also denominated Isotheral and Isocheimal lines; the former signifying lines of equal temperature for the summer season, and the latter lines of equal winter temperature. See Report of the British Association, 1832, pp. 217, 218.

† For observations on the extremes of heat and cold which have occurred in different regions; and relative to the mean temperature of the poles and the equator, see Book of Science, pt. i., *Pyronomics*, pp. 292—297; 2d edition, pp. 296—303. And for an account of the direction and extent of isothermal zones, the mean temperatures of days, months, and seasons, and the extreme temperatures of climates, see Pouillet Elém. de Physique et de Météorologie, tom. ii. pp. 628—638; and Encyclopædia Metrop., vol. iv., Meteorology.

33 feet in height, or of a column of mercury 30 inches high. Such is nearly the amount of the mean gravity of the atmosphere at the level of the sea.* Its relative gravitating force or pressure must of course decrease in ascending above the surface of the earth; but augmentations and diminutions of that force are observable at the same place, which must therefore arise from circumstances independent of local elevation. These alterations of atmospheric pressure may probably have a considerable effect on the animal creation. They are indicated by the rising or depression of a column of mercury, inclosed in a glass tube, forming the well-known instrument called a barometer. It has been computed, that the weight of air commonly pressing on the surface of the body of a man of middle size is about 30,000 lbs.. hence a variation of height in the mercurial column of only a single line must indicate an alteration of atmospheric pressure to the extent of about 84 lbs.

The variations of pressure that have been observed are either *periodical* or *occasional*. The horary variations are the most important. From the observations of M. Ramond, it appeared that the barometer attained its maximum height at 9 A. M. and at 11 P. M.; and its minimum at 4 A. M. and 4 P. M. These variations take place with greater regularity between the tropics than in Europe; and we learn, from the investigations of Humboldt, that near the equator the barometer attains a maximum at 9 A. M. and P. M., and a minimum at 3 or 4 A. M. and P. M. so constantly, that, in almost all states of the air, the height of the barometer will indicate the time of day. The causes of these horary oscillations are somewhat obscure; though it appears probable that they chiefly depend on temperature.

The occasional variations of atmospheric pressure seem to be intimately connected with the direction of the wind. They are greatly influenced by latitude. "At the equator they may be said to be almost reduced to nothing; for it rarely happens that any change takes place to interfere with the regular course of the diurnal tides. A hurricane creates almost the only exception. The amount of variability increases towards the poles, in a great measure owing, probably, to the irregularity of the winds beyond the tropics. The mean amount of variation may be stated at the equator at two lines, in France at ten lines, in Scotland at fifteen lines, throughout the year; but this quantity has its monthly oscillations."*

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* The mean height of the barometer at London for the year 1788 was 29.96 inches; for 1789, 29.79 in.; and for 1790, 29.98 in. Dr. Dalton's Meteorological Observations and Essays, 2d edit., 1834; from Philos. Transact.

WINDS.

The atmosphere may be considered as consisting of a multitude of concentric strata, the density of which decreases in proportion to their height above the surface of the sea. While an equilibrium exists between the different parts of the aërial mass, it remains calm and tranquil; but if the equilibrium be broken by any cause whatever, the mass becomes agitated, and that kind of motion in the air takes place which is termed wind. Among the general causes that destroy the equilibrium of the atmospheric strata, the most common are change of temperature or pressure, tides and great currents of water, the rotatory motion of the earth, the hygrometric or the electric state of the air, and the action of the sun and the moon. There are others the influence of which is less extensive, as earthquakes and the eruptions of volcanos.

Alteration of temperature is, perhaps, the most usual as well as the most important cause of aërial currents or winds. When one portion of a mass of air becomes more heated than those parts by which it is surrounded, it is rarefied and rendered lighter than before; so that it ascends to a higher level, while the adjacent colder and denser air rushing in to supply its place, streams of air tend from all points towards that where the partial vacuum has thus been formed. Professor Pouillet remarks, that Winds may be propagated by *impulsion* and by *aspiration*. We designate thus the two opposite modes, which ought to be carefully distinguished. Wind is propagated by impulsion, when it blows towards a place in one direction, and its progressive march is in the same direction: thus it is with the wind that issues from a pair of bellows, when the included air is compressed. Wind is propagated by aspiration, when the blast takes place in one direction, and the progressive march of the wind is in a contrary direction: this is what happens when the wind enters a pair of bellows in which the air is rarefied:

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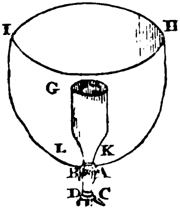
* Forbes on Meteorology—Report of Brit. Assoc. for 1832. p. 236.

for the blast rushes towards the nozzle, but the progressive march of the current is in an opposite direction; for the most distant points whence the air is drawn last receive the impression. This latter mode is not so unusual as might be imagined, as will appear from the phenomena of hurricanes. Wargentin has also made similar remarks on the winds in the north of Europe: he says, "When the wind proceeds from the west it is felt at Moscow earlier than at Abo, though the latter city is about 400 leagues farther westward than Moscow; and this wind does not reach Sweden till after it has blown over Finland."*

The manner in which winds are produced by changes of temperature may be illustrated by some simple experiments. The production of a current by lowering the temperature of a portion of air may be exhibited by means of the apparatus represented in the margin. Tie a piece of wet bladder over the mouth, C D, of the bottle, F G C D, after having poured into it as much water as will half-fill the neck when the bottle is inverted. Then take a large bladder, H K L I, and cut off the neck of it in such a manner as to leave a considerable opening, I H; and having made a hole in it at K L, the neck of the bottle is to be put through it, and the edges of the bladder must be tied fast round the bottle, so that no liquid may pass between the bladder and the bottle. Next throw a table-spoonful or two of common salt, and as much again of snow into the bladder, and upon the globular part of the bottle, and stir them together with a stick or wooden spoon. The snow and salt will then begin to melt, absorbing heat from the bottle with which they are in contact, and from the air within it, which will thus become cooled down to such a degree that it would freeze the water in the neck of the bottle if it reached above the part at which the bladder is tied; and as this might embarrass the experiment, but a small quantity of water should be introduced. Now the air within the bottle being condensed, and having its elasticity weakened by the deprivation of heat, while the external



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* Pouillet Elém. de Phys. Expér. et de Météorol. 2nde edit. 1832. tom. ii. pp. 715, 716.

air, which is not so cold, retains more expansive power, it will force its way into the bottle, and produce a current, on the bladder C D being punctured with a large pin at E. The air will then be seen rising up in bubbles, with considerable velocity, through the water in the neck of the bottle, till the equilibrium is restored between the external and the inclosed air.

The converse of the preceding experiment may be performed by slightly varying the apparatus already described. Take a bottle encompassed with a bladder, as before, and leaving it open, turn it upside down, with the mouth upon a plate or shallow dish, in which has been put a sufficient quantity of water to cut off the connexion between the air in the bottle and the external air. Then pour hot water upon the bottom of the bottle, and into the bladder surrounding it. The heat thus applied will expand the air in the bottle, which will issue out in a current, through the water in the plate, producing a mimic wind, that may be felt on holding the hand near the place where the air escapes.

These experiments show the different modes of propagation of aërial currents which Pouillet has indicated. The stream of air rising through the water into the first bottle (in which a partial vacuum has been formed by reduction of temperature) is obviously a current of aspiration; and that issuing from the second bottle, through the expansion of the included air by heat, is a current of impulsion. Each of these methods of propagation of blasts of wind may doubtless be sometimes distinguished; but it seems probable that winds in general should be regarded as the joint effect of expansion in one part of the atmosphere, and condensation in another.

Some interesting "Facts and Observations relating to the Winds, Waves, and other Phenomena, by which the Surface of the Sea is affected," were published by Captain Horsburgh, in Nicholson's "Journal of Natural Philosophy," which serve to show that a descending current of air may be propagated in various directions. He says, "I have several times, in calm weather, seen a cloud generate and diffuse a breeze on the surface of the sea, which spread in different directions from the place of descent. A remarkable instance of this occurred in Malacca Strait during a calm day, when a fleet was in company: a breeze commenced suddenly from a dense cloud, its centre of action seemed to be in the middle of the fleet, which was much scattered. The breeze spread in every direction from a centre, and produced a singular appearance in the fleet, for every ship hauled close to the wind as the breeze reached her, and, when it became general, exhibited to view the different ships sailing completely round a circle, although all hauled close to the wind."[*]

Captain Horsburgh afterwards says, "It frequently happens during a *ty-fong* in the China Sea, that the waves run in every direction; having the appearance of elevated mounts or pyramids, which infringe on each other with great violence. Ships are very liable to lose their rudders, when these pyramids strike against them; and the masts are endangered by the quick, turbulent motion proceeding from such heterogeneous impulse."[†] He also states, that the swell of the sea caused by a storm may be propagated with a greater mean velocity than the storm that causes it, and may therefore arrive on a coast before it, or come after the storm has ceased. These phenomena he attributes to the interference of contrary winds.

The sudden condensation of atmospheric vapour, from depression of temperature, must be one of the most powerful causes of winds; and hence they are often observed to accompany showers of rain. In the equatorial regions, water to the height of an inch sometimes falls over a large extent of territory. Suppose it to be 100 square leagues of surface: the vapour required to produce such a mass of water as would cover an area of 100 leagues square an inch deep, would occupy ten thousand times as much space; or, with the same superficial extent, would be 100,000 inches in thickness. That consequently would be the dimensions of the void that would result from such a condensation. Meteoric water, indeed, is not in this highly rarefied state, but in the state of vesicular vapour. Since that, however, is suspended in the atmosphere, it must possess an inferiority of density and consequent superiority of bulk, compared with liquid water; and its condensation into drops of rain must cause a partial vacuum, to fill which the air will rush in, probably from different directions, and excite great commotions in the atmosphere.[‡]

Winds may be distinguished as being either regular or variable.

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[*] Nicholson's Journal, 8vo. vol. xv. p. 11.

[†] Idem, p. 12.

[‡] Pouillet Elém. de Phys. et de Météorol., tom. ii. p. 716.

Among the former are the Trade Winds, between the tropics; the Monsoons, in the Arabian, Indian, and Chinese Seas; and the Sea and Land Breezes.

Over the Atlantic and Pacific Oceans, the trade winds blowing permanently westward, extend from 30° N. to 30° S. latitude. When the sun is on the equator, the trade winds, in sailing northward, veer more and more from the east towards the north; so that at their limit they become nearly NE.; and on the contrary, in sailing southward, they become at last almost SE. When the sun is near the Tropic of Cancer, the trade winds north of the equator become more nearly east than at other times, and those south of the equator more nearly south; the contrary phenomena are observed when the sun is near the Tropic of Capricorn. The trade wind becomes due east not exactly upon the equator, but about 4° N. of it.

These intertropical winds are the effects of the diurnal action of the sun in raising the temperature of the atmosphere over those points of the earth's surface where its beams are vertical combined with those arising from the earth's motion on its axis. The lower strata of the atmosphere near the equator becoming heated and rarefied by the sun during the day, form ascending currents spreading towards the poles; while under currents, from the north and south pole respectively, flow in to supply the partial vacuum caused by the condensation of the air over the equatorial space during the night.. The polar currents, which would otherwise meet and destroy each other at the equator or near it, are modified by the motion of the earth; for the air which is constantly passing from points where the surface of the earth moves most slowly, towards those where its velocity is greatest, cannot have exactly the same motion eastward with the part over which it is passing, and therefore must relatively to the surface beneath it form a current in an opposite direction. Thus, " the two general masses of air proceeding from both hemispheres towards the equator, as they advance are constantly deflected more and more towards the east, on account of the earth's rotation; that from the northern hemisphere, originally a north wind, is made to veer more and more towards the east, and that from the southern hemisphere in like manner is made to veer from the south towards the east: these two masses meeting about the equator, or in the torrid zone, their velocities north and south destroy each other, and they proceed afterwards with their common velocity from east to west, round the torrid zone, excepting the irregularities produced by the continents."*

Beyond the range of the trade winds, variable winds in general prevail. Though between the two there is a zone from 2 to 6 degrees in breadth, subject to the occurrence of dead calms, or sudden and violent tempests, caused apparently by the confluence of ascending and descending currents, between which there may sometimes be an equipoise, and at others rapid alternations of influence.

The Monsoons are periodical winds, blowing about six months in one direction, and six months in a contrary direction. From 10° to 23° S. latitude, in the Indian Ocean, the southern trade wind continues regularly from the east and south-east; but between 10° S. and the equator, north-west winds prevail from October to April, and south-west the rest of the year; while north of the equator, the wind is south-west in summer, and north-east in winter. These variations appear to be partly owing to the position of the sun, and partly to the directions of the great chains of mountains in the countries bordering on the seas over which the monsoons prevail.

Sea and Land Breezes are owing to the same grand cause that produces the trade winds. In the day, when the reflection of the sun's rays from the surface of the earth has heated the superincumbent air, it rises; and on the sea-coast, currents of cooler and denser air flow in from above the sea, to replace the ascending mass. At night the converse process takes place: the air over the land being then the coolest, the night breeze sets seaward, in general extending two or three leagues from the shore.

A diversity of local winds has been observed in different parts of the world, some of which have their peculiar designations. The Etesian is a northernly or north-easterly wind, which prevails very much in summer all over Europe. Pliny the Elder describes it as occurring regularly in Italy for forty days after the summer solstice. It is probably a part of the great under current moving from the north pole to the equator. The Sirocco, felt on the shores of the Mediterranean, is a hot blast from the south, prejudicial to the health of animals. Such also is the Harmattan, a warm, dry, east wind, which is perceived on the Guinea coast. The more deadly Kamsin, which occurs in Egypt; and the Simoom, or Samyel of the Arabs, a destroying wind, which is said to have proved fatal to whole caravans in crossing the deserts, are supposed to owe their properties to some pestilential vapours mixed with the air.

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* Dr. Dalton's Meteorological Observations and Essays, essay ii.

Tempests, hurricanes, and tornados, are atmospheric commotions of the more violent kind, chiefly taking place in intertropical latitudes. The destructive effects and extraordinary force of these concussions of the air, may be conceived from the statement which has been previously given of some of the phenomena of a hurricane in Guadeloupe.*

Whirlwinds, *trombes*, or syphons, are gyratory or vortical movements of the air, which have been attributed with some probability to the influence of electricity. They are confined to no country or climate; and occur at sea as well as on land. In fertile regions strong trees and buildings are sometimes torn up by the impetuous force of whirlwinds; in the deserts of Africa they produce moving pillars of sand, such as are picturesquely described by the celebrated traveller Bruce; and at sea they appear in the form of waterspouts.

"The relative velocity of winds," says Dr. Dalton, "may be best ascertained by finding the relative velocity of the clouds, which in all probability is nearly the same as that of the winds. The velocity of a cloud is equal to that of its shadow upon the ground, which in high winds is sometimes a mile in a minute, or sixty miles an hour; and a brisk gale will travel at the rate of twenty or thirty miles an hour."† The velocity of hurricanes has been variously estimated at from 100 to 300 feet in a second.‡

HYGROMETRY.

Many meteorological phenomena depend on the presence of water as a constituent part of the atmosphere. The volatilization and ascent of the aqueous fluid, continually taking place from the surface of the earth, produces fogs, mists, and clouds; and the corresponding processes of condensation and precipitation cause the formation of rain, snow, dew, and hoar-frost.

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* See Treatise on *Geology*, p. 335.

† Meteorological Observations and Essays, p. 90.

‡ See Lamouroux Géographie Physique, p. 103, for a table of the relative velocities of winds.

Moisture is found in the atmosphere, either in the state of invisible vapour, or in the form of minute globules, collected in masses of varying dimensions, from the miniature clouds that ascend from a basin of hot water, or hover above the surface of a small pond in an autumnal morning, to those vast fields of mist or haze that sometimes cover a wide tract of country. These collections of aqueous spherules, when they ascend to a certain height, constitute the different configurations of clouds; but the transition of aërial vapour from the visible to the invisible state is perpetually taking place; as also is the converse change of invisible vapour into cloud. The quantity of moisture in the atmosphere is thus continually varying,[*] its increase or decrease depending much on alternations of heat and cold. The air, however, is never perfectly dry, or quite deprived of water, even at the lowest possible temperature. According to Professor Leslie, "Air, at the freezing point, is capable of holding a portion of moisture equal to the 160th part of its own weight; at the temperature of 59°, the 80th part; at that of 86°, the 40th part; at 113°, the 20th part; and at that of 140°, the 10th part: so that the air has its dryness doubled at each rise of temperature answering to 27° of Fahrenheit. While the temperature, therefore, advances uniformly in arithmetical progression, the dissolving power which this communicates to the air mounts with the accelerating rapidity of a geometrical series."[†]

In tracing the causes of meteorological phenomena, it must obviously be a point of importance to ascertain the hygrometric state of the atmosphere within a given space, or the quantity of insensible moisture which a portion of air contains. The barometer indicates the total weight of an aërial column, depending partly on the invisible vapour which enters into the composition of the lower strata; but in order to discover the relative amount of that vapour, various circumstances must be taken into consideration, especially temperature and topical elevation. Hence more direct means are requisite to determine the proportion of moisture in the atmosphere; and for that purpose a great number of instruments have been invented, styled Hygroscopes or Hygrometers.

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[*] "The atmosphere is not of uniform composition; the quantity of aqueous vapour, one of its component parts, varies almost every hour of the day. It is subject to sudden increase, and as sudden diminution; and, in its ascent to higher regions, follows a very different law from that of the permanent elastic fluids."—Daniell, in Brande's *Journal of Science*, vol. viii. p. 324.

[†] Essays on Heat and Moisture.

A very simple apparatus may suffice to show the existence of water in the atmosphere. Many substances are naturally so far hygroscopic that their weight is sensibly influenced by the state of the air. Tobacco, sponge, salt, sugar, and other porous substances, imbibe moisture from a damp atmosphere, and consequently become relatively heavier than when the air is in a dry state. Sulphuric acid, potash, and muriate of lime, each powerfully attract water from the air when exposed to it, in almost any situation. Fibrous bodies, as hair and thread, become contorted and shortened longitudinally through their disposition to absorb atmospheric moisture. As the degrees of contraction which these bodies undergo admit of measurement, they have been very generally employed in the construction of hygrometers. M. de Saussure invented an instrument of this kind, which has been most extensively used in meteorological researches. It consists of a hair (rendered more susceptible of the influence of moisture by steeping it in a weak solution of potash), fixed at one extremity, and after being passed round a pulley, kept extended by a small weight at the other extremity. On the axis of the pulley an index, moving over a graduated arc of a circle, indicates the alternate contraction of length from absorption of moisture, and elongation from its evaporation; and thus affords, to a certain extent, a measure of the relative quantity of aërial vapour at different periods. De Saussure adopted some ingenious methods to determine the points of extreme moisture and extreme dryness for the scale of his hygrometer. He obtained the latter point by exposing the instrument under a bell-glass, within which the air had been as far as possible deprived of humidity, by means of concentrated sulphuric acid, or calcined muriate of lime (chloride of calcium); and the former, by placing it under a glass, the sides of which were wetted with distilled water, and standing over water. In spite, however, of the utmost precaution in the construction of these hygrometers, it has been found impossible to obtain two instruments that exactly correspond in their indications; nor will the hygroscopic power of an individual instrument remain long unaltered. If these defects could be avoided, De Saussure's hygrometer would only afford the means of comparing different degrees of humidity. "We might ascertain from it that the humidity of the air was at 60, 80, or 100 degrees; but we should learn nothing concerning the elastic force of the vapour contained in that air, and consequently should be unable to resolve the fundamental question which involves the grand object of hygrometry. For that purpose, it is necessary to determine what is the elastic force of the vapour which corresponds with each of the degrees of the hair hygrometer, and this determination is very difficult: because, for example, if the hygrometer marks 80° of humidity when the temperature is at zero, and 80° of humidity also when the temperature is at 30°, the corresponding elastic forces of this identical indication of the instrument cannot be equal. Hence further researches become requisite; and M. Gay-Lussac calculated what were the elastic forces of the vapour corresponding to different degrees of the hair thermometer for a given temperature, fixing on that of 10°. He found that when the hygrometer marks 100°, the elastic force is at its maximum, or 9.5 millimetres; at 60° the elastic force is reduced to $\frac{1}{4}$; and at 30° to $\frac{1}{7}$. Professor Pouillet remarks, that notwithstanding the important assistance afforded by the labours of M. Gay-Lussac, the hair hygrometer can but yield approximative estimates of the elastic force of the vapour contained in air, because the instrument is irregular in its indications, and liable to error.* It is, however, probably the least inaccurate of those hygrometers whose action depends on the change of dimensions in bodies, owing to their absorption of vapour; and as it has been very extensively employed by men of science in making meteorological observations, some notice of it seemed to be required.

Hygrometers of the kind just described can at best supply only a part of the information requisite towards determining the state of the atmosphere with respect to its aqueous contents. The quantity of invisible vapour in any mass of air must depend on the elastic force of the vapour, or its disposition to retain a gaseous form, and that again will be chiefly influenced by temperature. The precise object of hygrometry, then, should be to determine how much moisture the atmosphere, or a given portion of it, may contain at a certain temperature. This may be effected by ascertaining at what thermometrical degree a body of air begins to deposit its moisture, or form dew; and its temperature also being known, its quantity of moisture may be calculated. The degree of temperature at which moisture begins to be precipitated is termed the *dew-point*.[*] The manner in which it varies relatively to the state of the atmosphere as to heat and moisture, is well illustrated by one of Mr. Daniell's experiments. "The temperature of a room being 45°, I found the point of condensation in it to be 39°. A fire was lighted, the door and windows carefully shut, and no one allowed to enter. The thermometer rose to 55°, but the point of condensation remained the same. A party of eight persons afterwards occupied the room for several hours, and the fire was kept up. The temperature increased to 58°, and the point of condensation rose to 52°."[†]

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* Pouillet Elém. de Phys. et Météorol., tom. ii. pp. 737—741.

Among the instruments that have been invented to ascertain the hygrometric state of the atmosphere with relation to its temperature may be mentioned the hygrometers of Professor Daniell and of Professor Pouillet. Both consist of apparatus adapted to show the temperature of a body on the surface of which dew begins to form, and which may be compared with that of the air from which it is precipitated.[‡]

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[*] Dr. Dalton was, perhaps, the first English philosopher who pointed out the importance of the dew-point, as a hygroscopical phenomenon, in a series of Essays published in the Manchester Transactions, vol. v. First Series. But a kind of hygrometer involving this principle was long previously invented by an ingenious Frenchman. "M. le Roy prescrivoit, pour moyen hygrométrique, de tenir dans l'air un verre plein d'eau, et dont la température fût la même que celle de l'air; de refroidir lentement cette eau par une addition graduée et successive d'eau à la glace, et de noter le degré de froid auquel on commenceroit à voir à la surface du verre cette légere rosée qui indique la précipitation des vapeurs, et par conséquent la supersaturation de l'air contigu au verre. Il jugeoit l'air d'autant moins humide, qu'il falloit un degré de froid plus considérable pour operer cette précipitation."—*Sigaud de la Fond Elém. de Physique*, tom. iii. p. 354. V. Le Roy Essais sur l'Hygrométrie, p. 57.

[†] Brande's Journal of Science, vol. viii. p. 321.

[‡] For a descriptive account of Daniell's hygrometer, see papers in Brande's Journal of Science, vol. viii. p. 300; and Met. Essays and Obs. Pouillet's *Hygromètre à Capsule* is described in his Elém. de Phys. et de Météorologie, tom. ii. p. 733; and some others, constructed on similar principles, are noticed by Mr. Forbes, in Report of British Association for 1832.

Clouds.

Since the condensation of aërial vapour depends on the temperature of the atmosphere, it is manifest that it may exist in a much larger proportion in warm climates than in those that are colder. Thus the air in our cloudy climate is upon the whole less loaded with moisture than that beneath the clear sky of southern countries; and consequently more rain generally falls during a year at Naples than in London, and more at Calcutta than at Naples. At the equator the air, relatively to its temperature, contains less moisture than in the temperate zone, though the actual amount of moisture is larger. That is, the air, near the surface of the earth, under the line, has a greater capacity for moisture than air at the same height in colder regions; but in the latter, the actual quantity (though smaller in a given bulk of air), approaches more nearly to the point of saturation, without any where reaching that point; for when it does, precipitation takes place. "Hence, at the equator, the air immediately incumbent on the earth's surface must be comparatively very dry. Moreover, the cause which produces the dryness of the equatorial air, at the earth's surface, must all over the globe exert different degrees of the same influence. The air every where incumbent on the earth's surface must, therefore, always be under the point of saturation; the relative degree of dryness being highest under the equator, and gradually diminishing as we recede north or south toward the poles."*

Clouds consist of visible vapour, or meteoric moisture in the intermediate state between invisible vapour and palpable liquid. Their formation appears to be the result of the imperfect condensation of invisible vapour, from the intermixture of strata of air at different temperatures. Evaporation is perpetually taking place from the surface of the earth, not alone from seas, lakes, and rivers, but in some degree from the hard rock or the frozen soil.† The watery exhalations are usually imperceptible, unless when a rapid change of temperature occurs, as on a sudden thaw after a hard frost, when the damp earth and the waters throw off abundance of reeking vapour. At other times, the transfer of the aqueous fluid from the earth to the atmosphere, though not interrupted, is less distinctly observable. "During the heat of the day it rises from the surface of the land and waters, and reaches its point of condensation in greater or less quantities at different altitudes. Partial clouds are formed in different parallel planes, which always maintain their relative distances. The denser forms of the lower strata, as they float along with the wind, show that the greater abundance of precipitation has been at the first point of deposition, while the feathery shapes and lighter texture of the upper attest a rarer atmosphere. These clouds do not increase beyond a certain point, and often remain stationary in quantity and figure for many hours; but as the heat declines, they gradually melt away, till at length, when the sun has sunk below the horizon, the ether is unspotted and transparent. The stars shine through the night with undimmed lustre, and the sun rises in the morning in his brightest splendour. The clouds again begin to form, increase to a certain limit, and vanish with the evening shades. This gradation of changes, which we see so often repeated in our finest seasons, may at first seem contrary to the true principles; and the precipitations which occur with the *increase* of temperature and disappear with its *decline*, may, without reflection, be regarded as diametrically opposite to correct theory. But a little consideration will show that such conclusions would be untrue. The vapour rises, and is condensed; but in its descent falls into a warmer air, where it is again evaporated, and becomes invisible; and as the quantity of evaporation from the surface of the earth is exactly equal to supply this process above, the cloud neither augments nor decreases. When the sun declines, the ground cools more rapidly than the air; evaporation decreases, but the dissolution of the cloud continues. The supply at length totally ceases, and the cloud subsides completely away. The morning sun revives the exhalations of the earth, the process of their condensation and consequent cloudlike form commences, and they again undergo the same series of changes."*

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* Dr. Prout's Chemistry, Meteorology, &c., p. 287.

† See Book of Science, pt. i. p. 320; 2d edition, p. 326.

Clouds differ from fogs only in their superior elevation above the surface of the earth. "They are seldom a mile high in our climate in winter; in summer they may perhaps occasionally be two or three miles high. The thickness of a stratum of clouds, or distance from the under to the upper surface, is also variable, from a few yards to three or four hundred or more. A stratum of cloud of greater depth is probably of rare occurrence any where: it would produce a greater degree of darkness on the earth's surface than is ever observed."*

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* Daniell's Meteorological Essays and Observations, pp. 124, 125.

Different opinions have been proposed as to the constitution of clouds. They are usually regarded as consisting of little vesicles of water filled with humid air.† As to the cause of their ascent or suspension in the atmosphere, M. Gay-Lussac refers it to the impulsion of ascending currents, owing to the difference of temperature between the surface of the earth and that of the upper air; while M. Fresnel supposed that the solar heat absorbed by clouds, formed groups of miniature Montgofières, which rise to heights depending on their excess of temperature above that of the air. Dr. Dalton has advanced a different hypothesis, considering clouds as being composed of water only, in a state of extreme division. He says, "When a precipitation of vapour takes place, a multitude of exceedingly small drops form a cloud, mist, or fog: these drops, though eight hundred times denser than the air, at first descend very slowly, owing to the resistance of the air, which produces a greater effect as the drops are smaller."‡ This last view of the nature of clouds has been recently brought forward by Professor Stevelly, of Belfast, at the Edinburgh meeting of the British Association. He alleged that clouds were assemblages of spherules of water, the production of which might be accounted for by the laws of capillary attraction; and he very justly remarked, that notwithstanding their actual specific gravity compared with that of air, "the minute size of the cloudy spherules would alone be sufficient practically to suspend them, as even gold and platina may be so subdivided, as to descend with less than any assignable velocity."§

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* Dr. Dalton's Meteorolog. Observations and Essays, App. to 2d edit. Note [A.] The sequel of this note contains an instructive account of phenomena relating to Clouds, observed during excursions among the mountains of Cumberland and Westmorland.

† "On admet, en général, que les vapeurs qui constituent les nuages sont des *vapeurs vésiculaires*, c'est à dire, des amas de petits globules remplis d'air humide, tout-à-fait analogues aux bulles de savon."—*Pouillet Elém. de Phys. et de Météorol.*, tom. ii. p. 753.

‡ Meteorological Observations and Essays, p. 134.

§ Report of Prof. Stevelly's Observations, in Athenæum for Sept. 27, 1834.

Either of these theories *may* be employed to account for the phenomena; but as Professor Pouillet remarks, "We at present do not possess sufficient data concerning the real constitution of clouds, and the properties of the vapours or the different elements which compose them, on which to ground a satisfactory explanation of their various appearances."[*]

MODIFICATIONS OF CLOUDS.

The ever-changing varieties of form which clouds exhibit to the eye of the observer, seem to bid defiance to all attempts at classification. The task, however, has been undertaken by Mr. Luke Howard, who, after a long series of meteorological researches, formed a systematic arrangement of clouds, distinguishing them by names characteristic of their general structure and mode of production. The classification and terminology proposed by this ingenious philosopher have since been adopted by many writers both at home and on the continent; and Mr. Howard himself, after eighteen years' experience, thus states his confidence in the propriety of his method. "I do not find a necessity either to make additions to this little system, or to retrench any of its parts. Some subordinate distinctions may, indeed, at a future period be found useful; but until the classification, as it is, be generally adopted, its simplicity must form its most powerful recommendation, and its conformity to nature. It is in the form and structure, carefully considered with due reference to situation, that the observer will find the basis of a correct judgment; and he will do well to wait, at first, for several successive appearances of each modification, to which he will thus at length find the definition apply in all its parts."[†]

The modifications of clouds are distinguished into three principal and distinct formations, and four composite kinds, which, together with some varieties, are represented in the accompanying plate. The simple forms are the *Cirrus*, in which the vapours have the appearance of loose, narrow bands of parallel or diverging feathery fibres; the *Cumulus*, exhibiting heaped masses of a globular or conical shape; and the *Stratus*, forming

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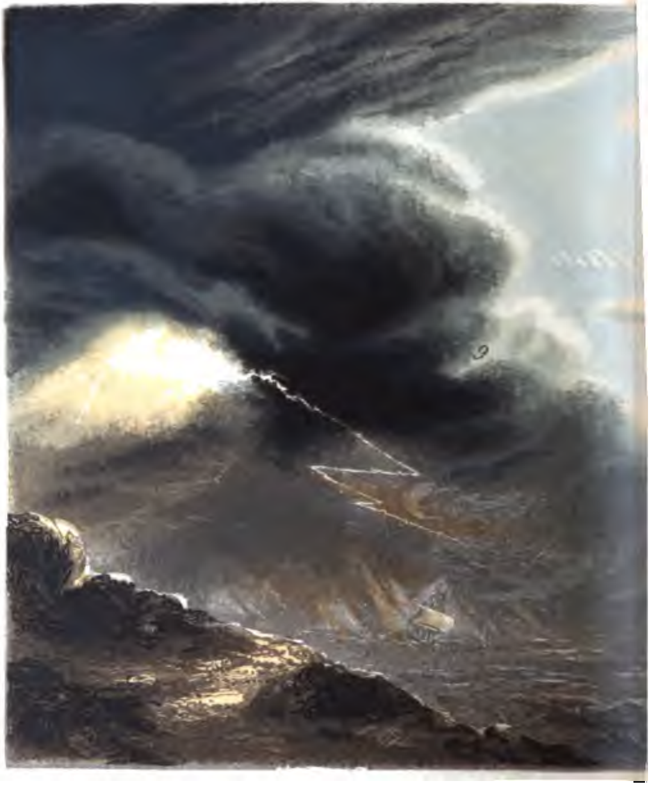
[*] Elém. de Phys. et de Météorol., tom. ii. p. 754.

[†] The Climate of London deduced from Meteorological Observations, p. 1.



MODIFICAT

1 LINEAR CIRRUS
2 MARE'S-TAIL CIRRUS
3 CYMOID CIRRUS
4 CIRRO CUMULUS
5
6

Engraved and PRINTED IN OIL

[illegible]

D STRATUS 7 CUMULUS 9 NIMBUS
LED CIRRO-STRATUS 8 CUMULO-STRATUS

URS by G. Baxter, 29, King Square, London.

extended level sheets of cloud. The composite clouds are the *Cirro-cumulus*, consisting of collections of small but well-defined orbicular masses, or little cumuli; the *Cirro-stratus*, in horizontal or somewhat oblique sheets, having a light, fibrous appearance above, and a concave or undulated surface below; the *Cumulo-stratus*, generally flattened at the base, and heaped above with overhanging protuberances; and the *Nimbus*, composed of dense continuous masses, forming a canopy of vapour dissolving below into rain.

Dr. Thomas Forster, who has long been an industrious observer of atmospheric phenomena, and has distinguished himself by his writings on meteorology, has adopted Mr. Howard's system, which he has endeavoured to familiarize by the addition of English names for the several modifications of clouds. To the statement of these terms may be properly added a few notices of the modes of formation of the different varieties, and of the inferences that may be drawn from their appearance relative to changes of weather.

CIRRUS, or CURLCLOUD. (See *Plate, fig*. 1, 2.)—This modification with its varieties may be distinguished by its fleecy lightness, fibrous structure, and instability of form; seldom long preserving the same appearance. It commonly occupies the higher regions of the air. In variable and warm weather, with gentle breezes in summer, long obliquely descending bands of cirri are sometimes seen connecting masses of other modifications, previously to rain. After a continuance of fine clear weather, the cirrus may be observed crossing the sky at a great height, like a white thread, the extremities of which seem lost in the horizon. This is called the *Linear Cirrus* (*fig*. 1). When several of these long clouds are connected by transverse or oblique processes, they have been termed, from their netlike arrangement, *Reticular Cirri*. The most usual form of the cirrus is that called the *Comoid*, or *Mare's-tail Cirrus* (*fig*. 2), which commonly occurs in variable weather, indicating the approach of wind or rain. When carefully observed, the cirri will be found to exhibit signs of internal commotion, without any change of place; though sometimes the fibres seem to wave gently to and fro. This happens most frequently in those large and lofty cirri, with rounded heads and long pointed tails, which are common in summer and autumn during the prevalence of dry easterly winds.

CUMULUS, or STACKENCLOUD (*fig*. 7).—This cloud is readily distinguished by its irregularly hemispherical figure, having generally a level base. It is produced by the gathering of detached masses, which then appear stacked or piled together. Its formation may be most advantageously traced in fine settled weather. About sunrise, small, thinly-scattered specks of cloud may be perceived; which, as the sun ascends, increase in bulk, coalesce, and at length form the complete cumulus. It has been termed the *cloud of day*, as it generally dissolves in the evening, separating first into small fragments, and retracing the steps of its formation in a reversed order. The more regularly-rounded cumuli, of a whitish colour, which reflect a bright silvery light when opposite the sun, are the harbingers of fine weather; but those of a more indeterminate figure, with a dark hue and irregular fleecy protuberances, prognosticate rain.

STRATUS, or FALLCLOUD.—The stratus is nothing more than that bed of vapour which covers the surface of the earth during the absence of the sun, or when its rays are impeded, sometimes creeping as a mist over the valleys and low lands, and disappearing soon after sunrise; and at others, hovering in the shape of a dingy fog, at a small elevation in the air, during one or perhaps several days. In its usual form of a summer-evening mist, it owes its origin to the nocturnal depression of temperature in the lower region of the atmosphere. It may be observed in a fine evening, after a hot day, when the cumuli which have prevailed through the day decrease, that a white haze gradually forms close to the ground, and veils its surface. About midnight it attains its utmost density, and disappears towards sunrise. It has hence been called the *cloud of night*. In autumn the longer continuance of this cloud marks the diminution of the sun's power. But in winter it sometimes assumes the form of a dense fog, shrouding in dismal darkness every object on the earth, especially in the atmosphere of large cities; the obscurity being augmented by the intermixture of smoke with the watery vapour. In January, 1814, one of these fogs pervaded the air over a great part of the south and west of England, for about a fortnight. The stratus is often found to be positively electrified; and hence it does not wet objects in contact with it. This modification must not be confounded with some varieties of cirrostratus, which resemble it in appearance; but the latter wets every thing it touches, and thus the two forms may be distinguished.

CIRROCUMULUS, or SONDERCLOUD (*fig.* 4).—The name of this cloud indicates its affinity to two of the principal forms. It differs from some varieties of the cirrostratus, by the superior density and compactness of its component nubeculæ, and the greater diversity of arrangement. At the approach of thunder-storms cirrostrati appear in masses of a denser structure, more rounded shape, and in closer order than at other times. In rainy, changeable weather, these clouds have a light fleecy texture, and variable figure, being scarcely to be discriminated from cirrostrati. In summer the cirrocumulus forebodes heat; and in winter, the breaking up of frost, and approach of mild, wet weather.

Cirrostratus, or Wanecloud (*fig.* 5, 6).—From its disposition to rapid alteration of figure and subsidence, this kind of cloud has derived its English appellation. It is remarkable for its shallow depth relatively to its horizontal extent; while in other respects it is constantly varying. It originates more frequently from the cirrus than from any other modification; and sometimes after descending from a higher station, and assuming its characteristic figure, it changes again into cirri; but more commonly it either evaporates, or unites with some other kind of cloud, producing cumulostratus, nimbus, and then falling in rain. Besides its common appearance as a long, plain streak of cloud, tapering towards the extremities (*fig.* 5), it assumes the form of the *Mottled Cirrostratus* (*fig.* 6), constituting what is called the mackerel-back sky of summer evenings, which has been proverbially reckoned a sign of dry weather. The *Cymoid Cirrus* (*fig.* 3) is accounted a variety of the cirrostratus. It is composed of waving bars or streaks, either arranged so as to form lines, or otherwise disposed. It is said to be a sure indication of approaching storms. Another variety of the cirrostratus is that large shallow veil of cloud which occurs especially towards night, and through which the sun and moon appear but indistinctly. Halos, parhelia, &c., usually are formed by peculiar refractions of the light of those bodies in this variety of cloud. It betokens rain or snow.

Cumulostratus, or Twaincloud (*fig.* 8).—This modification of cloud is produced by the accumulation of other kinds, as the cirrus and cumulus. The cumulus, driven by the wind, becoming retarded in its course, grows denser, spreads laterally, and swells out into a dark, irregular mass. Sometimes a number of cumuli unite at the base, from which heaps of vapour rise in the form of mountain peaks, or detached rocks. The cumulostrati, which give birth to storms of hail or thunder and lightning, often look black and lowering, especially before the shower of hail or rain begins to fall. Occasionally, the clouds of this modification evaporate, or the mass separates into cumuli; but more commonly their appearance is followed by that of the nimbus, producing rain or snow.

NIMBUS, or RAINCLOUD (*fig.* 9).—Any of the other modifications of clouds may form and again disperse, or become evanescent; but the nimbus is a constant precursor of a storm. It may be best observed when showers fall at a distance, and the nimbus can be seen in profile. The progress of its formation may be inferred from what has been just described, under the preceding modification. The cumulostratus having been formed, sometimes goes on increasing in density till the whole horizon is veiled in portentous darkness. Shortly after which, the lowering sky assumes a grey obscurity, denoting a new arrangement of the particles of vapour in the cloudy mass. The nimbus is then formed, and rain descends. The shower continues till the nimbus is exhausted, and other modifications of cloud reappear: the cirrus, the cirrostratus, or perhaps the cirrocumulus, are seen aloft, floating amidst the blue sky; and the remaining cumulus, no longer retarded, sails along with the wind nearer the surface of the earth.

Rain, Snow, and Hail.

The immediate cause of *Rain* is obviously the intermixture of masses of air whose common temperature is insufficient to keep suspended their joint amount of moisture, part of which is therefore precipitated. Contending currents in the atmosphere bring, suddenly, into mutual contact vast fields of moist air, and the aqueous particles coalescing form drops, which, if the temperature is above the freezing point, descend in liquid showers. The size of the drops of rain probably depends on the degree of rapidity with which condensation takes place; and the rate at which they descend must be influenced by the relative height of the clouds, the action of the wind, and their own magnitude.

The mean quantity of rain that falls in different parts of the world varies considerably according to local circumstances. Among these are temperature, distance from the sea, and position with respect to mountain chains. According to Humboldt, nearly six times as much rain falls at the equator as in 60° N. latitude. But in the tropical regions the rains, though vastly more abundant than in cold climates, are much less frequent; and in the former, the rains are periodical. Mountainous tracts are visited with more copious and frequent showers in general than plains; and in some countries little or no rain falls, as in Egypt, the fertility of which depends on the periodical inundations of the Nile.

It has been repeatedly remarked, that in any given situation the quantity of rain is greatest at the least elevation: thus more might be collected within an area 12 inches square at the bottom than at the top of a high tower, all other circumstances except the height above the ground being equal. An experimental investigation of the cause of this phenomenon has been undertaken by Mr. John Phillips, of York, an account of which may be found in the Reports of the British Association for 1833. The hypothesis which he proposes, as a probable inference from the result of his researches, is, "that the whole difference in the quantity of rain at different heights above the neighbouring ground, is caused by the continual augmentation of each drop of rain from the commencement to the end of the descent, as it traverses successively the humid strata of air of a temperature so much lower than that of the surrounding medium as to cause the deposition of moisture upon its surface." Mr. Phillips purposes to pursue the inquiry, with a view towards the completion of the theory of this curious subject, the patient investigation of which, as he justly remarks, cannot fail to give us new and penetrating views into the constitution of the atmosphere.*

When the temperature of the region of the air in which the resolution of the cloudy vapour into water takes place happens to be below the freezing point, the globules in the act of union become congealed into needle-shaped or spicular crystals, which form little hexagons almost infinitely modified; and these again combining as they descend, produce flakes of *Snow*. Sometimes the frozen masses are very small, constituting *Sleet*.

If the globules of rain are completely formed before congelation takes place, and they traverse in their descent a stratum of dry air at a very low temperature, they reach the ground in the state of *Hail.* "Hailstones are often of considerable dimensions, exceeding sometimes the length of an inch. They may, therefore, fall with a velocity of 70 feet per second, or at the rate of about 50 miles in the hour. Striking the ground with such impetuous force, it is easy to conceive the extensive injury which a hail-shower may occasion in the hotter climates. The destructive power of these missiles, in stripping and tearing the fruits and foliage, increases besides in a faster ratio than the momentum, and may be estimated by the square of their velocity multiplied into their mass. This fatal energy is hence the fourth power of the diameter of the hailstone."*

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* Report of British Association for 1833, pp. 410, 412.

The celebrated Volta ascribed the formation of hail to electricity, and proposed to defend tracts of country from hail-storms by rods on the principle of lightning conductors. These hail-rods or *paragrêles*, as they were called, were tried in France and Switzerland, but apparently with little advantage.

Dew, Hoar-frost, and Ground-ice.

The precipitations of water from the atmosphere, already described, depend on changes of temperature in the air; but there are others frequently taking place in consequence of depression of temperature in solid bodies. In the summer season, in clear, calm nights, the surface of the earth and growing plants are found at sunrise covered with globules of limpid moisture, so that the trees and hedges glitter in the first rays of the sun as if they were hung with multitudes of brilliant diamonds or transparent pearls. This phenomenon, so often described by poets as well as philosophers, and so familiarly known to all who inhabit the country, constitutes *Dew;* which in some situations occurs so copiously as to supply the want of rain. The circumstances under which it is precipitated are so different from those which accompany the separation of moisture from the air in the state of rain, that philosophers were long at a loss to account for it. Among the causes assigned for its production one of the most plausible was electricity.

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* Leslie on Heat and Moisture.

At length, however, Dr. W. C. Wells, by an ingeniously-conducted series of experiments, ascertained that dew is chiefly owing to the radiation of heat from the substances on which it is deposited. Hence it is that dew never forms during nights which are both cloudy and windy; and if in the course of a night, the weather from being serene should become dark and stormy, the dew which may have been produced will disappear. Grass, leaves of vegetables, or other bodies, must be quite exposed to the sky in order to enable them to receive dew; and therefore the slightest shelter will prevent its deposition on the covered surface. The quantity of dew must necessarily depend not entirely on the degree of radiation at any one time and place, but also on the amount of moisture present in the air. Perfect stillness in the atmosphere, therefore, is not always so favourable to the deposition as gentle motion; by means of which, after one mass of air has been deprived more or less of its moisture, by contact with radiating bodies, other portions of air from which it has not been separated may be successively brought near to those bodies, which may thus receive repeated deposits. Any considerable agitation, however, approaching to wind, causes the precipitation to cease.

These and many other circumstances connected with the occurrence of dew admit of a complete and lucid explanation, by referring them to the property of radiation. Light fibrous substances, as filaments of gossamer, wool, thread, cotton, hair, grass, and low plants, both dead and living, are among the best radiators, and receive dew most readily; while rocks, bare earth, and considerable masses of water, have less disposition to part with their heat in the same manner, and therefore remain free from dew.

Hoar-frost is merely frozen dew, owing either to powerful radiation, when the atmosphere itself has a temperature above the freezing point, but the radiating substances part with their heat so fast as to fall below it, and thus the moisture freezes on them as soon as it is precipitated: or the congelation may be accomplished and preserved by a depression of temperature in the air below 32° Fahrenheit. Glass is an excellent radiator of heat; and hence it often receives depositions of hoar-frost in winter, incrusting its surface sometimes with elegant frost-work, bearing a fanciful resemblance to trees and landscapes. Some of the simpler forms of hoar-frost are exhibited in the following figures.

The trees and hedges also in the cold season display yet more beautiful assemblages of snowy crystals, the complicated figures of which it would be useless to attempt to trace. Hoar-frost in the spring sometimes destroys the buds and flowers of plants, and literally deprives the gardener of the fruit of his labour. It had been long known that tender vegetables and opening buds might be protected from its deposition by a very slight shelter; but it is only since the discoveries of Dr. Wells have been promulgated that the manner in which such shelter acts (namely, by preventing radiation) has been properly understood.

The production of *Ground-ice*, that is, ice formed at the bottom of rivers, is a phenomenon that has often attracted the notice of philosophers, and given rise to different hypotheses. Mr. T. A. Knight, in a paper published in the Philosophical Transactions, attributes the formation of ice in such situations to particles originally congealed at the surface, and afterwards carried to the bottom by the eddies of streams.* Neither this nor other theories that have been advanced can be considered as satisfactory. The phenomena are well described in a paper by Mr. Richard Garnett, of Blackburn, in Lancashire, published in Brande's Journal of Science in 1818; but that gentleman does not propose any new mode of accounting for the existence of ground-ice. He remarks, however, that it never occurs but under peculiar atmospherical circumstances.[*] He adds, that "the immediate cause of the formation of this ice seems to be the rapid diminution of temperature in the stone or gravel in the bed of the river (*on which it is deposited*), connected with sudden changes in the state of the atmosphere."[†]

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* See Abstracts of Papers in Philos. Trans., vol. ii. p. 46.

Experiments, which could be best prosecuted in frosty weather, would be requisite to develop the cause of the formation of ground-ice. It may, however, be not improbably attributed to the acquisition by stones or gravel, in consequence of radiation of heat, of a temperature below the freezing point, while the water passing over those substances was somewhat warmer. It may be stated as an argument in favour of this supposition, that ground-ice is found only in clear, running water, through which it may be conceived radiation might take place.

Such are the principal meteorological phenomena dependant on the relation of the atmosphere to heat and moisture. This short essay has been necessarily restricted to notices of the most remarkable facts and observations concerning these subjects; but those who may be desirous of obtaining more ample information, will find in the works of Leslie, Dalton, Daniell, Pouillet, Howard, and other authors here quoted or referred to, the results of the latest and most accurate researches; by means of which they may, if they think proper, extend their acquaintance with this interesting branch of physical science.

There are various other atmospheric phenomena which are treated of in books relating to meteorology. These are chiefly of two classes, namely, those which may be explained by means of the laws of Optics, and those which appear to depend on Electro-magnetism. Among optical or photonomical phenomena, there are few more curious than the Mirage, Looming, and the Fata Morgana, or more beautiful than the Rainbow; and of these some notices will be found in the treatise on Optics, in the former volume of this work. Notwithstanding the brilliant discoveries that have been made within the last forty or fifty years relative to Electricity, we are yet by no means able to trace the full extent of its influence over the atmosphere. That it is the cause of lightning is, however, universally admitted; and to this subject the attention of the reader has been directed in the treatise on Electricity.

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[*] Brande's Journal, vol. v. p. 269.

[†] Idem, p. 273.

The Aurora Borealis is mentioned in treating of Magnetism, with which its phenomena appear to be intimately connected. It may be added, that Dr. Dalton, in an Essay on the Aurora, has, with his accustomed skill and science, endeavoured to trace the occurrence of this meteor to the presence of magnetic particles or effluvia in the air.

Perhaps there are no atmospheric phenomena more singular or problematical than the descent of Aerolites or Meteorites, as they have been termed. The fact of their fall was long doubted, but at present seems to be indisputably ascertained. They all consist chiefly of magnetic iron, having a remarkable analogy of composition. Their origin is quite uncertain; and the different explanations of their appearance that have been attempted are perhaps equally improbable. Some suppose them to have been formed in the air, an hypothesis which D'Aubuisson rejects as untenable; others consider them as the products of volcanos in the moon, projected into our atmosphere; and according to Chladni, they are fragments of planets which have burst in pieces amid the ethereal space. With this brief notice of this hitherto inexplicable phenomenon we conclude this treatise on Meteorology.

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